



Cambridge International AS & A Level

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CHEMISTRY

9701/41

Paper 4 A Level Structured Questions

October/November 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) Disodium phosphate, $(\text{Na}^+)_2(\text{HPO}_4^{2-})$, reacts with an acid to form monosodium phosphate, $\text{Na}^+(\text{H}_2\text{PO}_4^-)$.

- (i) Identify the ions that are a conjugate acid–base pair in this reaction, using the formulae of the species involved.

conjugate acid

conjugate base

..... [1]

- (ii) Define buffer solution.

..... [2]

- (iii) Write **two** equations to show how a mixture of $(\text{Na}^+)_2(\text{HPO}_4^{2-})$ and $\text{Na}^+(\text{H}_2\text{PO}_4^-)$ can act as a buffer solution.

equation 1

equation 2 [2]

- (iv) Identify **one** inorganic ion that acts as a buffer in blood.

..... [1]

- (b) Compound **E** is the hydroxide of a Group 2 element. Compound **E** is a strong alkali.

2.63 g of **E** is dissolved in water to make 250 cm^3 of solution **F**. Solution **F** has a pH of 13.09 at 298 K.

- (i) Show that the concentration of hydroxide ions in solution **F** is 0.123 mol dm^{-3} .

[2]

- (ii) Explain why the concentration of compound **E** in solution **F** is $0.0615\text{ mol dm}^{-3}$.

..... [1]

- (iii) Use the concentration given in (ii) to identify compound **E**.

compound **E** [1]





(c) Compound **E** is much more soluble than magnesium hydroxide.

A saturated solution of magnesium hydroxide in water has a concentration of $1.40 \times 10^{-4} \text{ mol dm}^{-3}$ at 298 K.

Calculate the solubility product, K_{sp} , of magnesium hydroxide. Include units.

$K_{\text{sp}} = \dots\dots\dots \text{ units } \dots\dots\dots [3]$

(d) Explain why compound **E** is much more soluble than magnesium hydroxide.

.....

.....

.....

.....

.....

.....

.....

..... [3]

[Total: 16]





- 2 (a) Predict and explain the variation in enthalpy change of hydration for the ions F^- , Cl^- , Br^- and I^- .

.....

 [2]

- (b) Fig. 2.1 shows an incomplete energy cycle involving calcium fluoride, CaF_2 .

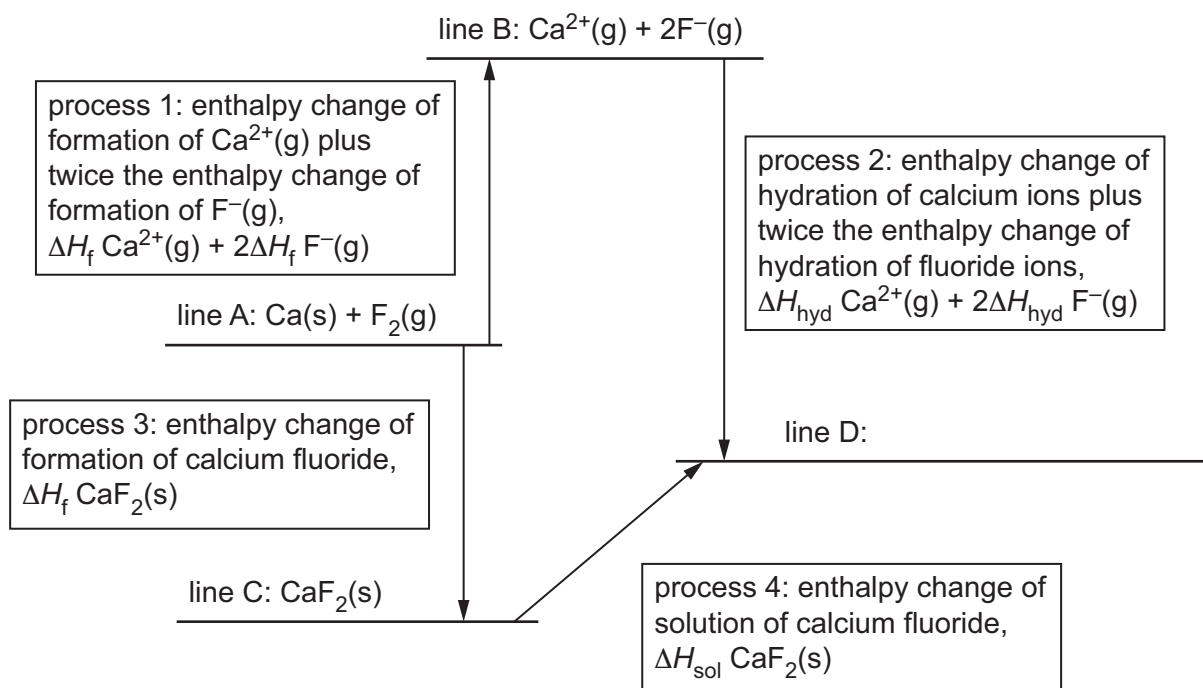
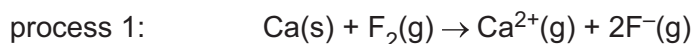


Fig. 2.1

- (i) Complete line D. Include state symbols. [1]
- (ii) The value of the enthalpy change for process 1 can be calculated using the values of **five** other enthalpy changes which are **not** referred to in Fig. 2.1.



Identify these **five** other enthalpy changes, using either names or symbols.

.....

 [2]





(iii) Define lattice energy, ΔH_{latt} .

.....

 [2]

(iv) Complete the expression to give the mathematical relationship between ΔH_{latt} of calcium fluoride and the enthalpy changes for processes 1 and 3.

$$\Delta H_{\text{latt}} =$$

[1]

(c) Use data from Table 2.1 to calculate a value for the hydration energy, ΔH_{hyd} , of fluoride ions, $\text{F}^-(\text{g})$.

Table 2.1

	value / kJ mol^{-1}
enthalpy change of solution of calcium fluoride, $\text{CaF}_2(\text{s})$	+13
overall enthalpy change of process 1 in Fig. 2.1	+1395
enthalpy change of formation of calcium fluoride	−1214
enthalpy change of hydration of $\text{Ca}^{2+}(\text{g})$	−1650

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

(d) Define entropy.

.....
 [1]





(e) At 298 K, the Gibbs free energy change, ΔG , for the solution of compound **T** is $+6.00 \text{ kJ mol}^{-1}$.

The enthalpy change of solution, ΔH_{sol} , of compound **T** is $+30.0 \text{ kJ mol}^{-1}$ at 298 K.

Calculate the value of the entropy change, ΔS , for the solution of compound **T** at 298 K.

$$\Delta S = \dots\dots\dots \text{ J K}^{-1} \text{ mol}^{-1} \quad [2]$$

(f) Predict whether compound **T** becomes more or less soluble as the water is heated from 298 K to 360 K. Explain your answer.

.....

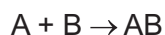
..... [1]

[Total: 14]





- 3 (a) A and B react together to give product AB.



When the concentrations of A and B are both $0.0100 \text{ mol dm}^{-3}$, the rate of formation of AB is $7.62 \times 10^{-4} \text{ mol dm}^{-3} \text{ s}^{-1}$. When the concentrations of A and B are both $0.0200 \text{ mol dm}^{-3}$, the rate of formation of AB is $3.05 \times 10^{-3} \text{ mol dm}^{-3} \text{ s}^{-1}$.

- (i) Complete the **three** possible rate equations that are consistent with these data.

rate = ...

rate = ...

rate = ...

[2]

- (ii) Choose **one** of the rate equations you have written in (i), and calculate the value of the rate constant, k . Include the units of k .

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

- (iii) Explain why it is **not** possible to calculate a value for the half-life, $t_{\frac{1}{2}}$, of this reaction using the value of the rate constant k calculated in (ii) and the equation $k = 0.693/t_{\frac{1}{2}}$.

.....

.....

..... [1]





(b) Catalysts may be homogeneous or heterogeneous.

- (i) Identify **two** metals that act as heterogeneous catalysts in the removal of NO_2 from the exhaust gases of car engines.

..... and [1]

- (ii) Iron acts as a heterogeneous catalyst in the Haber process.

Describe the mode of action of this iron catalyst.

.....

 [2]

- (iii) Fe^{2+} ions act as a homogeneous catalyst in the reaction between $\text{I}^-(\text{aq})$ and $\text{S}_2\text{O}_8^{2-}(\text{aq})$.

Write equations for the **two** reactions that occur when $\text{Fe}^{2+}(\text{aq})$ is added to a mixture of $\text{I}^-(\text{aq})$ and $\text{S}_2\text{O}_8^{2-}(\text{aq})$.

equation 1 $\text{S}_2\text{O}_8^{2-} + \dots\dots\dots$

equation 2 $\dots\dots\dots$ [2]

- (iv) Explain the difference between a homogeneous catalyst and a heterogeneous catalyst.

.....

 [1]

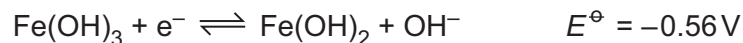


(c) Fe^{2+} ions can be oxidised to Fe^{3+} ions under alkaline conditions by suitable oxidising agents.

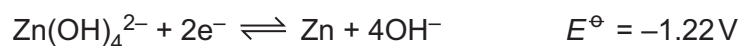
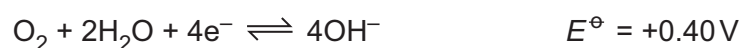
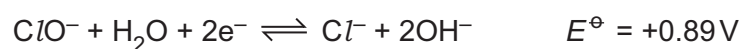
- (i) Iron is a transition element. Explain why iron forms stable compounds in both the +2 and the +3 oxidation states.

..... [1]

- (ii) The half-equation for the reduction of Fe^{3+} under alkaline conditions, and its $E^\ominus$ value, are shown.



Four more half-equations for reactions under alkaline conditions, and their $E^\ominus$ values, are shown.



Select **two** oxidising agents that can oxidise Fe^{2+} ions to Fe^{3+} ions under alkaline conditions.

Write an equation, and give the $E^\ominus_{\text{cell}}$ value, for **each** of the **two** reactions that occur.

oxidising agent 1:

equation:

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

oxidising agent 2:

equation:

$$E^\ominus_{\text{cell}} = \dots\dots\dots \text{V} \quad [4]$$

[Total: 16]





4 Transition metal atoms and transition metal ions form complexes by combining with ligands.

(a) Explain why transition elements form complex ions.

.....
 [1]

(b) Co^{2+} ions form complex ion **G**.

Each **G** ion contains **two** Co^{2+} ions, both of which are octahedrally coordinated.

Each **G** ion contains one O_2 molecule, which donates one pair of electrons to **each** Co^{2+} ion, and one NH_2^- ion, which donates one pair of electrons to **each** Co^{2+} ion.

The remaining ligands are NH_3 molecules.

(i) Deduce the formula of complex ion **G**. Include its overall charge.

formula of **G** [2]

(ii) The d-orbitals of the Co^{2+} ions present in complex ion **G** are split. State the number of d-orbitals that are at a higher energy level and the number of d-orbitals that are at a lower energy level in **each** Co^{2+} ion.

number of d-orbitals at a higher energy level	
number of d-orbitals at a lower energy level	

[1]

(iii) Co^{2+} ions form a different complex ion, **M**.

Each **M** ion contains **two** Co^{2+} ions, both of which are octahedrally coordinated, but the ligands are different from the ligands in **G**.

Explain why **G** and **M** have different colours.

.....

 [2]



- (c) Cadmium forms complex ion **X**, $[\text{Cd}(\text{NH}_3)_4]^{2+}$.

When a solution containing CN^- ions is added to an aqueous solution of **X**, a ligand exchange reaction takes place, forming complex ion **Y**. **Y** contains no NH_3 ligands and no H_2O ligands.

Y is in a much higher concentration in the mixture than **X**.

The oxidation state and coordination number of cadmium do **not** change in this reaction.

- (i) Write an ionic equation for this reaction, using the formulae of the complex ions.

..... [2]

- (ii) Cadmium forms complex ion **Z** in the same oxidation state and with the same coordination number as in **X**. All the ligands in **Z** are Cl^- ions.

When $\text{NaCl}(\text{aq})$ is added to a solution of **X**, very little **Z** forms.

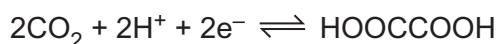
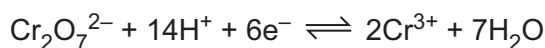
Write the **three** cadmium complexes, **X**, **Y** and **Z**, in order of increasing stability constant, K_{stab} .

.....
smallest value of K_{stab} largest value of K_{stab} [1]

- (d) Ethanedioate ions, $\text{C}_2\text{O}_4^{2-}$, form complexes with transition element ions.

The concentration of $\text{C}_2\text{O}_4^{2-}$ ions can be found by reaction with acidified $\text{Cr}_2\text{O}_7^{2-}$ ions. $\text{C}_2\text{O}_4^{2-}$ ions are protonated and form HOOCCOOH molecules which are oxidised by $\text{Cr}_2\text{O}_7^{2-}$.

The half-equations are shown.



- (i) Construct an equation for the reaction between acidified $\text{Cr}_2\text{O}_7^{2-}$ and HOOCCOOH .

..... [1]

- (ii) A 25.0 cm^3 sample of a solution of $\text{Na}_2\text{C}_2\text{O}_4$ reacts with exactly 16.20 cm^3 of an acidified solution of $0.0500\text{ mol dm}^{-3}$ $\text{K}_2\text{Cr}_2\text{O}_7$.

Calculate the concentration of the solution of $\text{Na}_2\text{C}_2\text{O}_4$.

$[\text{Na}_2\text{C}_2\text{O}_4] = \dots\dots\dots \text{mol dm}^{-3}$ [2]

[Total: 12]





- 5 The shapes of four different complexes, **P**, **Q**, **R** and **S**, are shown in Table 5.1.

The symbol **J** represents an atom or ion of a transition element.

The symbol **L** is used to represent a monodentate ligand.

Table 5.1

P	Q
R	S

- (a) Label **one** bond angle on **each** of complexes **P**, **Q**, **R** and **S**, and identify the size of the angle in degrees. [2]

- (b) Identify the shapes of complexes **P**, **Q**, **R** and **S**.

P

Q

R

S [2]

- (c) Two **L** ligands are exchanged with two **different** monodentate ligands **X** and **Y** in each of complexes **P**, **Q**, **R** and **S**.

Identify all the complexes which form new complexes that show geometrical isomerism.

..... [1]

- (d) Three **L** ligands are exchanged with three **different** monodentate ligands **X**, **Y** and **Z** in each of complexes **P**, **Q** and **R**.

Identify all the complexes which form new complexes that show optical isomerism.

..... [1]

[Total: 6]





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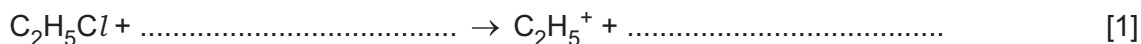
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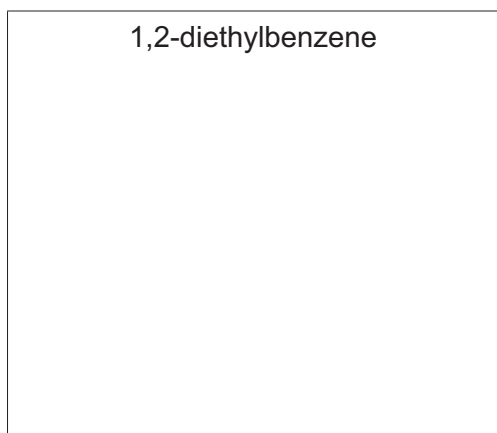
- 6 Benzene, C_6H_6 , reacts with chloroethane, C_2H_5Cl , in the presence of a suitable catalyst to form ethylbenzene, $C_6H_5C_2H_5$. In the presence of the catalyst, the ion $C_2H_5^+$ is formed. This ion reacts with benzene.

- (a) Complete the equation for the reaction of C_2H_5Cl with this catalyst to form $C_2H_5^+$ as one product.



- (b) Ethylbenzene reacts with more C_2H_5Cl , forming a mixture containing 1,2-diethylbenzene and 1,4-diethylbenzene.

- (i) Draw the structures of 1,2-diethylbenzene and 1,4-diethylbenzene.



[1]

- (ii) Explain why there is very little 1,3-diethylbenzene in the product mixture.

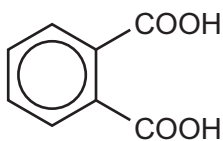
.....

..... [1]



(c) 1,2-diethylbenzene can be oxidised to benzene-1,2-dioic acid, $\text{C}_6\text{H}_4(\text{COOH})_2$.

benzene-1,2-dioic acid



(i) State the reagent and conditions used for this reaction.

..... [1]

(ii) Complete the overall equation for this reaction.

An atom of oxygen from the oxidising agent is represented as [O].

All of the atoms in the two ethyl groups are fully oxidised in this reaction.

..... + ... [O] $\rightarrow$ $\text{C}_6\text{H}_4(\text{COOH})_2$ + ... + ...
(1,2-diethylbenzene) [2]

(iii) Predict the number of peaks in the carbon-13 NMR spectrum of benzene-1,2-dioic acid.

..... [1]





- (d) The proton (^1H) NMR spectra of ethylbenzene, $\text{C}_6\text{H}_5\text{C}_2\text{H}_5$, in CDCl_3 and of benzene-1,2-dioic acid, $\text{C}_6\text{H}_4(\text{COOH})_2$, in CDCl_3 are shown. They have **not** been identified.

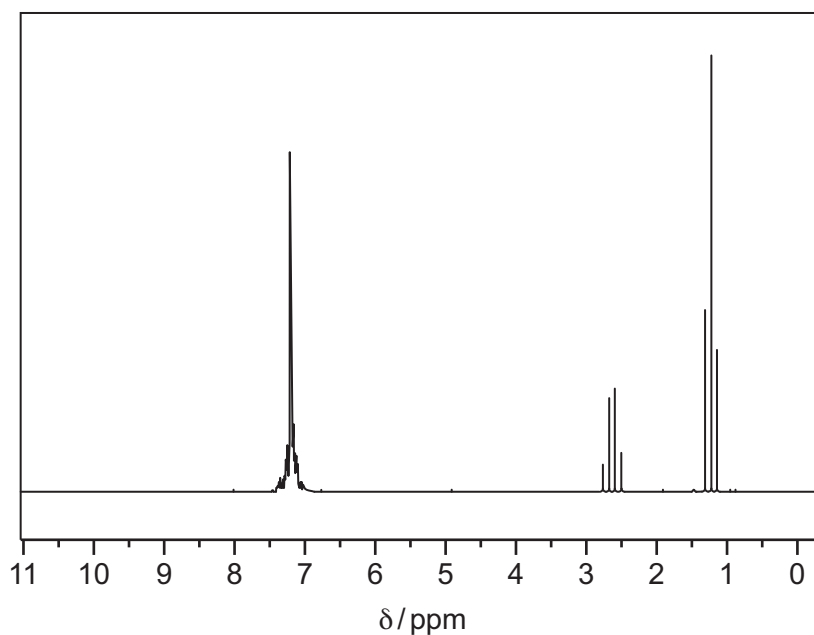


Fig. 6.1

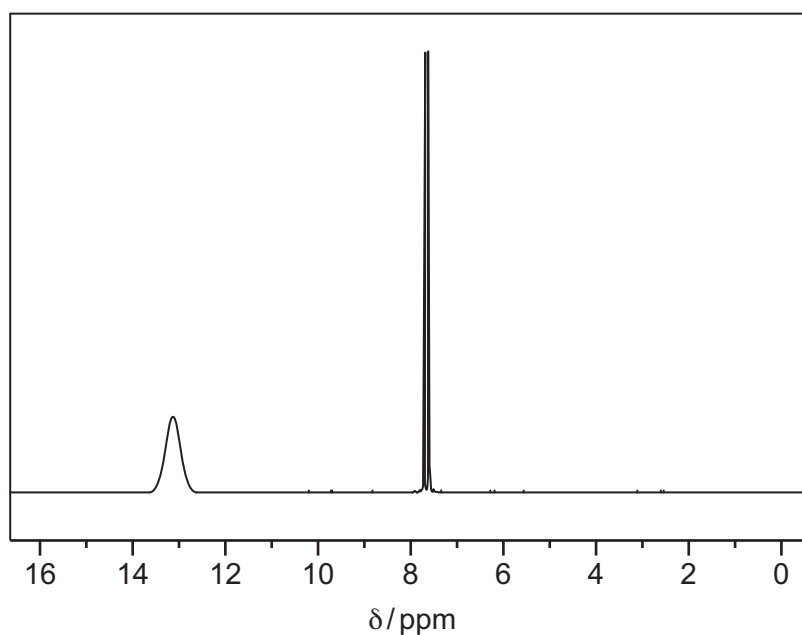


Fig. 6.2

- (i) Explain the use of CDCl_3 , instead of CHCl_3 , as the solvent when obtaining these spectra.

..... [1]



- (ii) Identify the substance shown by the spectrum in Fig. 6.1, and complete Table 6.1.

substance

Table 6.1

	peak at $\delta = 1.2$	peak at $\delta = 2.6$
name of splitting pattern		
group responsible for peak		
explanation of splitting pattern		

[3]

- (iii) Identify the substance shown by the spectrum in Fig. 6.2, and complete Table 6.2.

substance

Table 6.2

	peak at $\delta = 7.8$	peak at $\delta = 13.1$
group responsible for peak		

[1]

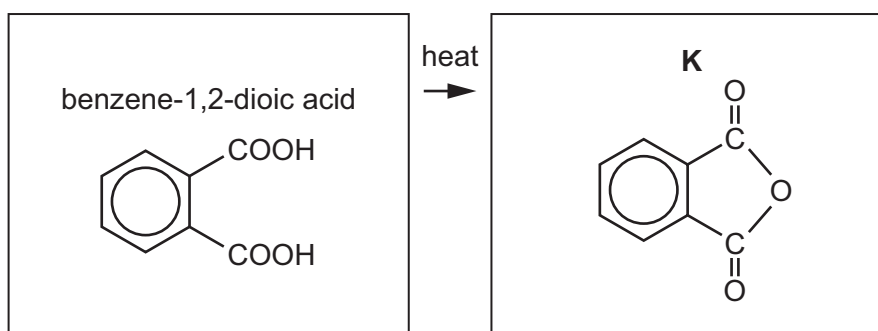
- (iv) When D_2O is used as a solvent, the spectrum obtained is different from the spectrum in Fig. 6.2.

Describe this difference and explain your answer.

.....

 [1]

- (e) Benzene-1,2-dioic acid can be used to produce **K**.



Suggest the name of this type of reaction.

..... [1]





7 A reaction scheme is shown in Fig. 7.1.

The reagents needed for reaction 2 and reaction 3 are stated.

Reaction 5 takes place when $\text{C}_2\text{H}_5\text{NH}_2$ is mixed with compound **V**. No special conditions are required.

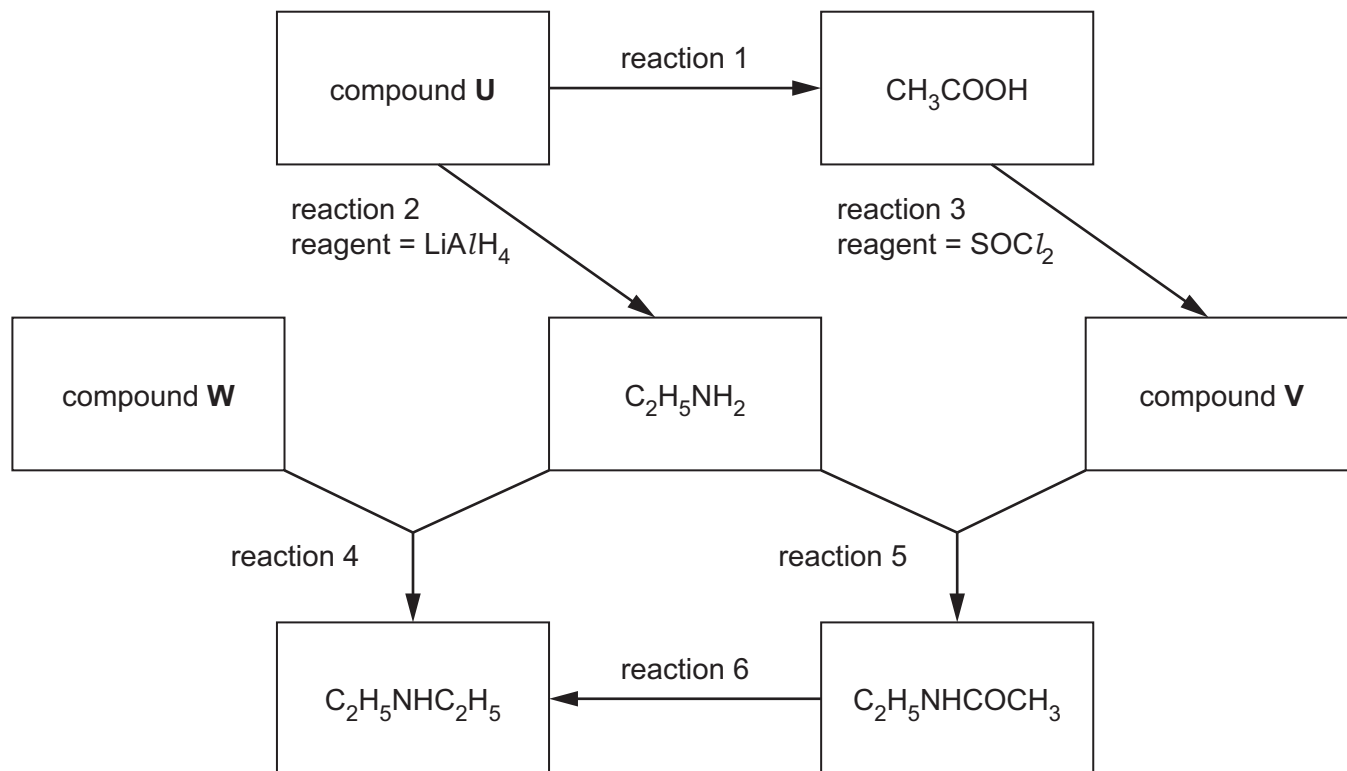


Fig. 7.1

(a) Identify compound **U** which contains only three elements.

..... [1]

(b) Describe the reagents and conditions for reaction 1.

..... [1]

(c) Identify compound **V**.

..... [1]

(d) Complete the equation for reaction 3.

$\text{CH}_3\text{COOH} + \text{SOCl}_2 \rightarrow$ [1]

(e) Identify compound **W**.

..... [1]

(f) Describe the conditions for reaction 4.

..... [1]





(g) Suggest the reagent needed for reaction 6.

..... [1]

(h) Complete Table 7.1 by adding the reaction numbers, 1, 2, 3, 4, 5 and 6, to the right-hand column. Use the reaction numbers given in Fig. 7.1.

Each of the numbers 1, 2, 3, 4, 5 and 6 should be used once only.

Table 7.1

type of reaction	reaction number(s)
hydrolysis	
addition	
reduction	
substitution	

[4]

(i) Compare the basicities of $\text{C}_2\text{H}_5\text{NHCOCH}_3$, $\text{C}_2\text{H}_5\text{NHC}_2\text{H}_5$ and NH_3 .

Explain your answer.

.....
 most basic least basic

 [4]

[Total: 15]





- 8 (a) An aqueous solution of phenol, $\text{C}_6\text{H}_5\text{OH}$, is acidic at 298 K.

Explain why phenol is more acidic than water.

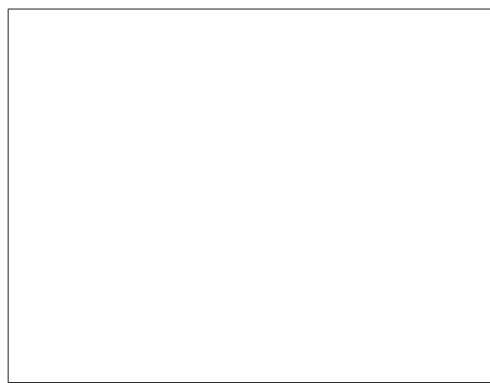
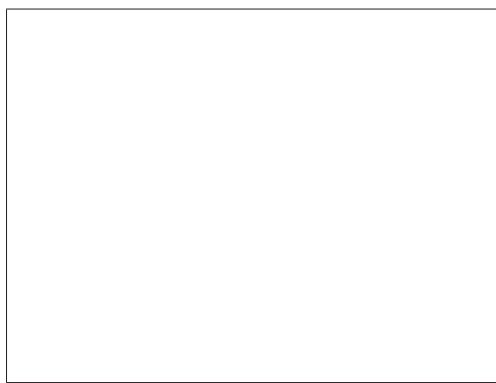
.....

 [2]

- (b) (i) Name the **two** products formed when phenol reacts with an excess of $\text{Br}_2(\text{aq})$.

..... and [1]

- (ii) Draw the structures of the **two** isomeric organic products, with $M_r = 139$, that are formed when phenol reacts with $\text{HNO}_3(\text{aq})$ at room temperature.



[1]

- (iii) Write the equation for the reaction between phenol, $\text{C}_6\text{H}_5\text{OH}$, and sodium metal.

..... [1]

- (c) Phenol can be produced from phenylamine in a two-step synthesis.



Describe the reagents and conditions needed in each step.

step one:

reagents

conditions

step two:

reagents

conditions

[2]

[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								2 He helium 4.0	

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Cambridge International AS & A Level

CANDIDATE
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CHEMISTRY

9701/42

Paper 4 A Level Structured Questions

October/November 2024

2 hours

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

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INFORMATION

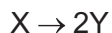
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This document has **24** pages. Any blank pages are indicated.



- 1 (a) The equation for reaction 1 is shown.

reaction 1



Reaction 1 is first order with respect to the concentration of X. The half-life of the reaction, $t_{\frac{1}{2}}$, is 900 s at 20 °C.

- (i) A solution of X with a concentration of $0.180 \text{ mol dm}^{-3}$ is prepared at 20 °C. Calculate the average rate of reaction 1 over the first 1800 s.

average rate of reaction 1 = ... [2]

- (ii) Complete the rate equation for reaction 1.

rate = ... [1]

- (iii) Show that the rate constant, k , is $7.70 \times 10^{-4} \text{ s}^{-1}$ at 20 °C.

[1]

- (iv) Calculate the initial rate of reaction 1 when the concentration of X is $0.150 \text{ mol dm}^{-3}$.

Include units.

rate = ... units [2]

- (b) Catalysts may be homogeneous or heterogeneous.

- (i) Platinum is a transition element. Explain why transition elements behave as catalysts.

.....

 [1]

- (ii) Name the metal catalyst in the Haber process and explain why it is a **heterogeneous** catalyst.

metal
 [1]



- (iii) Platinum acts as a heterogeneous catalyst in the removal of nitrogen dioxide, NO_2 , from the exhaust gases of car engines.

Describe the mode of action of a platinum catalyst in this process.

.....

 [2]

- (iv) NO_2 acts as a homogeneous catalyst in the oxidation of atmospheric sulfur dioxide, SO_2 .

Write equations for the **two** reactions that occur.

equation 1
 equation 2 [1]

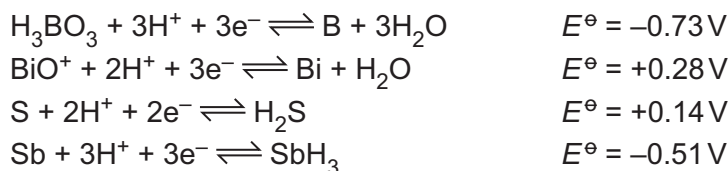
- (c) SO_2 dissolves in water, forming H_2SO_3 .

H_2SO_3 can be oxidised under acidic conditions.

The relevant electrode reaction and its $E^\ominus$ value are shown.



Four more half-equations for reactions occurring under acidic conditions, and their $E^\ominus$ values, are shown.



Select the oxidising agent that could oxidise H_2SO_3 to SO_4^{2-} ions under acidic conditions.

Write an equation, and give the $E^\ominus_{\text{cell}}$ value, for the reaction that occurs.

oxidising agent

equation

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

[3]

[Total: 14]

[Turn over]





- 2 (a) Predict and explain the variation in enthalpy change of hydration for the ions Na^+ , Mg^{2+} and Al^{3+} .

.....

.....

.....

.....

..... [3]

- (b) Fig. 2.1 shows an incomplete energy cycle.

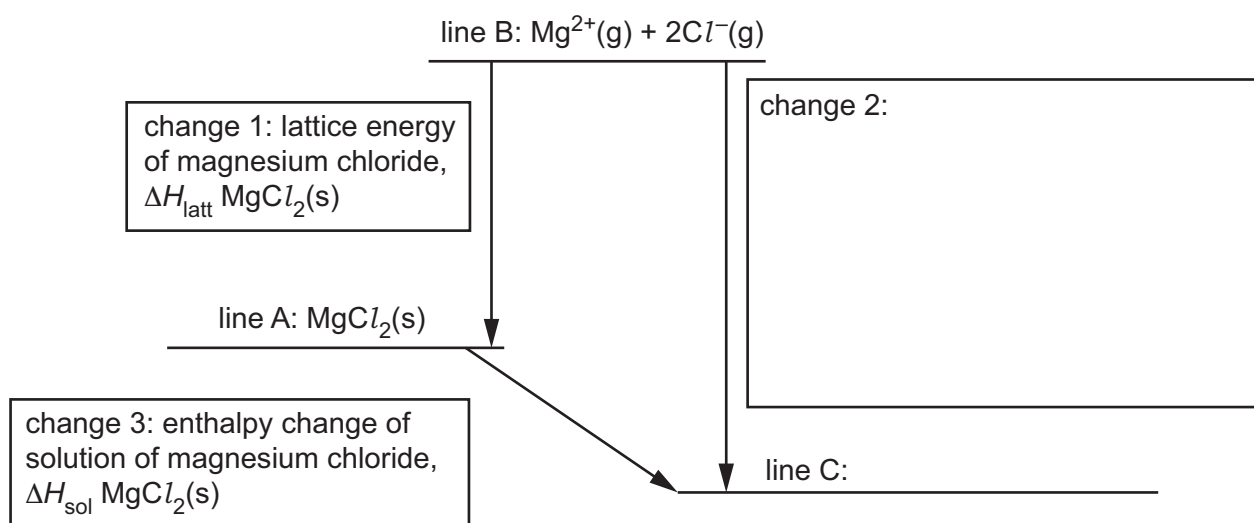


Fig. 2.1

- (i) Complete line C on Fig. 2.1. Include state symbols. [1]

- (ii) Use **both** words **and** symbols to identify change 2 on Fig. 2.1.

Use changes 1 and 3 as examples of how this should be done.

[2]



- (iii) Calculate a value for the lattice energy of magnesium chloride, $\Delta H_{\text{latt}} \text{MgCl}_2(\text{s})$, by selecting and using appropriate data from Table 2.1.

Table 2.1

energy change	value / kJ mol^{-1}
enthalpy change of solution of magnesium chloride	–155
enthalpy change of formation of magnesium chloride	–642
first ionisation energy of magnesium	+736
second ionisation energy of magnesium	+1450
electron affinity of chlorine	–349
enthalpy change of hydration of Mg^{2+}	–1920
enthalpy change of hydration of Cl^-	–364

$$\Delta H_{\text{latt}} \text{MgCl}_2(\text{s}) = \dots\dots\dots \text{kJ mol}^{-1} \quad [3]$$

- (c) Define entropy.

.....
 [1]

- (d) At 25°C the enthalpy change of solution of compound **Z** is $+26 \text{ kJ mol}^{-1}$. The entropy change of solution of **Z** at the same temperature is $+52 \text{ J K}^{-1} \text{ mol}^{-1}$.

Calculate the value of the Gibbs free energy change, ΔG , for the solution of **Z** at 25°C .

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





- (e) (i) Use your answer to (d) to predict whether or not **Z** is soluble in water at 25 °C. Explain your answer.

.....
..... [1]

- (ii) Predict whether **Z** becomes more or less soluble as the water is heated from 25 °C to 95 °C. Explain your answer.

.....
..... [1]

[Total: 14]

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3 (a) The pH of a saturated solution of calcium hydroxide is 12.35 at 298 K.

- (i) Show that the concentration of hydroxide ions in a saturated solution of calcium hydroxide is $0.0224 \text{ mol dm}^{-3}$ at 298 K.

[2]

- (ii) Use data given in (i) to calculate the solubility product, K_{sp} , of calcium hydroxide at 298 K.

Include the units of K_{sp} in your answer.

$K_{\text{sp}} = \dots\dots\dots \text{units} \dots\dots\dots$ [3]

- (iii) A spatula measure of solid calcium chloride is stirred into a sample of saturated calcium hydroxide solution. All of the calcium chloride dissolves.

Describe **one** other observation that would be made and give an estimated value of the pH of the solution obtained.

Explain **both** your answers.

observation

pH of solution

explanation

[3]

- (iv) Calcium hydroxide reacts with dilute sulfuric acid to form calcium sulfate. Barium hydroxide behaves in a similar way, forming barium sulfate.

Explain why calcium sulfate is more soluble in water than barium sulfate.

.....

.....

.....

.....

..... [3]





- (i) Write an equation for the reaction of calcium with CH_3COOH .

..... [1]

- Pair 1 should consist of organic species.

pair 1:
conjugate acid conjugate base

pair 2:
conjugate acid conjugate base

[2]

- (iii) Write the expression for the K_a of CH_3COOH .

$$K_a =$$

[1]

- (iv) The concentration of calcium ethanoate, $(\text{CH}_3\text{COO})_2\text{Ca}$, in mixture **D** is $0.394 \text{ mol dm}^{-3}$.
The concentration of CH_3COOH in mixture **D** is $0.270 \text{ mol dm}^{-3}$.

The K_a of CH_3COOH is $1.74 \times 10^{-5} \text{ mol dm}^{-3}$ at 298 K.

Calculate the pH of mixture **D**.

pH = ... [2]

- (v) Write **two** equations to show how mixture **D** can act as a buffer solution.

equation 1

equation 2

[2]

[Total: 19]



- 4 Transition metal atoms and transition metal ions form complexes by combining with species called ligands.

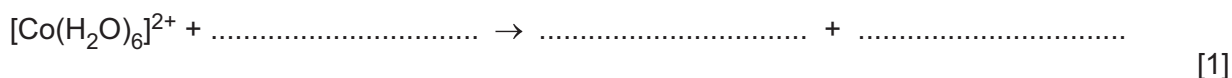
- (a) When NaOH(aq) is added to an aqueous solution containing $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ a precipitation reaction occurs accompanied by a colour change.

In this reaction two of the water ligands each lose one H^+ ion. The H^+ ions are gained by OH^- ions from the NaOH(aq).

- (i) State the colour change seen in this precipitation reaction.

from to [1]

- (ii) Complete the ionic equation for this precipitation reaction.



- (iii) This precipitation reaction can also be described as a **different** type of reaction.

Name this type of reaction.

..... [1]

- (b) **L** is an uncharged tridentate ligand. **L** donates three lone pairs to a metal atom or ion.

Cobalt forms an octahedral complex ion, **E**, with **L**. Complex ion **E** has a 2+ charge.

- (i) Give the formula of **E**.

..... [1]

- (ii) Identify the oxidation state of cobalt in **E**.

..... [1]

- (iii) The d-orbitals of the cobalt atom or ion present in **E** are split in energy.

State the number of d-orbitals that are at a higher energy level and the number of d-orbitals that are at a lower energy level.

number of d-orbitals at a higher energy level	
number of d-orbitals at a lower energy level	

[1]

- (iv) Define the term non-degenerate d-orbitals.

.....
 [1]



- (c) The mineral chromite contains a compound which has the formula FeCr_nO_4 . The oxidation state of iron in FeCr_nO_4 is +2.

A sample of 4.18 g of FeCr_nO_4 is dissolved in an excess of sulfuric acid. The resulting solution is made up to 250 cm^3 . This is solution **F**.

All the Fe^{2+} ions in 25.0 cm^3 of solution **F** are oxidised to Fe^{3+} ions by exactly 18.7 cm^3 of $0.0200\text{ mol dm}^{-3}$ KMnO_4 .

One MnO_4^- ion reacts with five Fe^{2+} ions. Assume no other oxidation reaction occurs.

- (i) Write an equation for the reaction of Fe^{2+} ions with MnO_4^- ions in acid solution.

..... [1]

- (ii) Calculate the number of moles of Fe^{2+} ions in 25.0 cm^3 of solution **F**.

number of moles of Fe^{2+} ions = ... [2]

- (iii) Calculate the M_r of FeCr_nO_4 and use your answer to deduce the value of n .

M_r of FeCr_nO_4 = ...

value of n = ... [2]

[Total: 12]





- 5 Ni^{2+} ions form a number of different complex ions, including $[\text{Ni}(\text{H}_2\text{O})_6]^{2+}$, $[\text{Ni}(\text{NH}_3)_6]^{2+}$ and $[\text{Ni}(\text{en})_3]^{2+}$.

The abbreviation *en* represents 1,2-diaminoethane. The numerical values of two stability constants, K_{stab} , are given in Table 5.1.

Table 5.1

complex	K_{stab}
$[\text{Ni}(\text{NH}_3)_6]^{2+}$	4.8×10^7
$[\text{Ni}(\text{en})_3]^{2+}$	2.0×10^{18}

- (a) Complete the expression for the K_{stab} of $[\text{Ni}(\text{en})_3]^{2+}$.

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

[1]

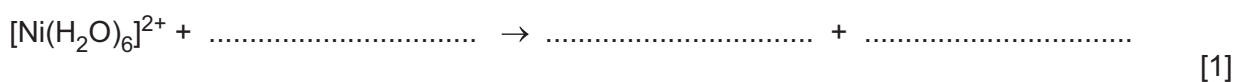
- (b) A solution of $[\text{Ni}(\text{H}_2\text{O})_6]^{2+}$ is added to a solution that contains $0.10 \text{ mol dm}^{-3} \text{ NH}_3$ and $0.10 \text{ mol dm}^{-3} \text{ en}$.

- (i) Predict which complex ion, $[\text{Ni}(\text{NH}_3)_6]^{2+}$ or $[\text{Ni}(\text{en})_3]^{2+}$, is present in the resulting mixture in the highest concentration. Explain your answer.

complex ion present in largest concentration = ...

explanation [1]

- (ii) Complete the equation for the ligand exchange reaction occurring in (i).





(c) Complete Fig. 5.1 to show the three-dimensional structures of the two isomers of $[\text{Ni}(\text{en})_3]^{2+}$.

Use N  N to represent the *en* ligand.

Name the type of isomerism shown.

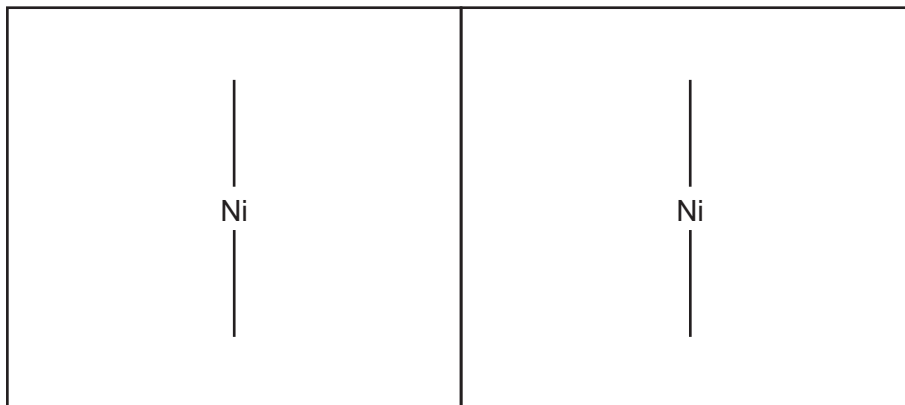


Fig. 5.1

type of isomerism shown [3]

[Total: 6]





6 Fig. 6.1 shows two reactions of ethanedioic acid, HOOC-COOH.

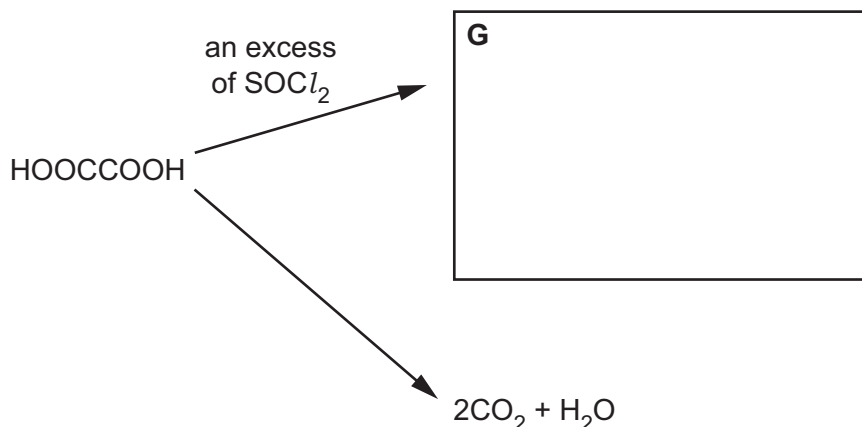


Fig. 6.1

(a) (i) Draw the organic product **G** in the box in Fig. 6.1.

[1]

(ii) In Fig. 6.1, SOCl_2 is given as the reagent that reacts with HOOC-COOH to produce **G**.

Identify a different reagent that also reacts with HOOC-COOH to produce **G**.

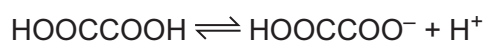
..... [1]

(b) Identify **two** different reagents that oxidise HOOC-COOH to form carbon dioxide and water.

.....

..... [2]

(c) HOOC-COOH ionises as shown.



HOOC-COOH is a much stronger acid than methanoic acid, HCOOH.

Suggest an explanation for this difference in acidity.

.....

.....

..... [2]



- (d) Benzene-1,4-dicarboxylic acid, $\text{HOOC}_6\text{H}_4\text{COOH}$, can be made from benzene, C_6H_6 , in two steps as shown in Fig. 6.2.

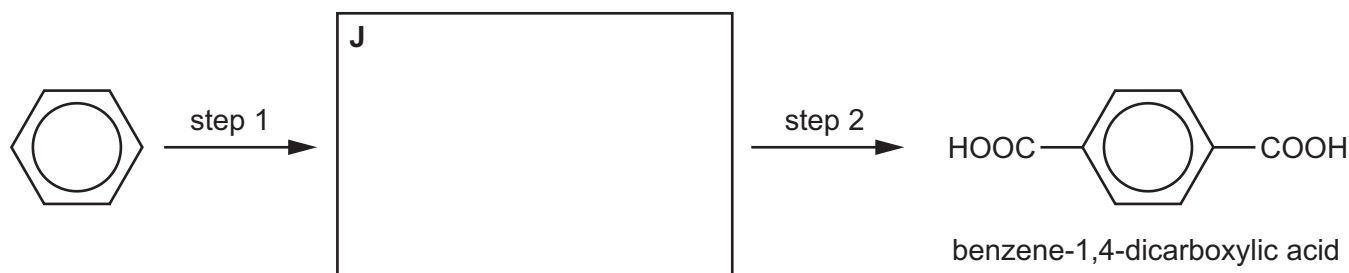


Fig. 6.2

- (i) Suggest the identity of **J** by drawing its structure in the box in Fig. 6.2. [1]
- (ii) Identify the reagents and conditions for step 1 and step 2.
- step 1
- step 2 [2]
- (iii) Draw the structure of exactly **one** repeat unit of the polymer formed when benzene-1,4-dicarboxylic acid reacts with ethane-1,2-diol, $\text{HOCH}_2\text{CH}_2\text{OH}$. The linkage formed between the monomers should be shown fully displayed. [2]
- (iv) State the type of polymerisation that occurs when benzene-1,4-dicarboxylic acid reacts with ethane-1,2-diol and name the linkage formed between the monomers.
- type of polymerisation
- linkage [1]

[Total: 12]



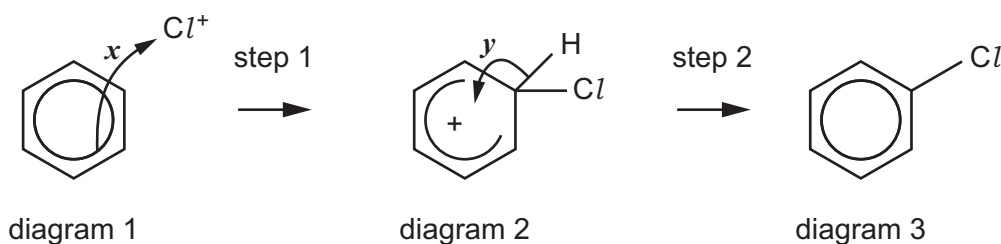


- 7 Benzene reacts with chlorine gas to form chlorobenzene. This reaction can be described as the reaction between benzene molecules and Cl^+ ions. The Cl^+ ions are formed by adding a suitable catalyst to the chlorine gas.

(a) Give the name or formula of a catalyst that can be used for this reaction.

..... [1]

(b) The mechanism for this reaction is shown.



(i) The movement of a pair of electrons is represented by x in diagram 1.

- State where this pair of electrons is **before** step 1 takes place.

.....

- State where this pair of electrons is **after** step 1 has taken place.

.....

[2]

(ii) The movement of another pair of electrons is represented by y in diagram 2.

- State where this pair of electrons is **before** step 2 takes place.

.....

- State where this pair of electrons is **after** step 2 has taken place.

.....

[2]

(c) There are six carbon atoms in diagram 2.

State how many of these carbon atoms are sp hybridised, sp^2 hybridised, and sp^3 hybridised.

sp hybridised

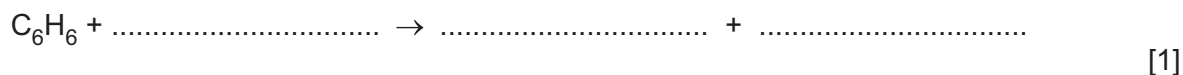
sp^2 hybridised

sp^3 hybridised

[1]



(d) Complete the equation for this reaction between benzene and chlorine.



(e) The mechanism for this reaction is electrophilic substitution.

Complete the following sentence. Write formulae in the gaps provided.

During this reaction, the electrophile is and a atom
in benzene is substituted by a atom. [1]

(f) Chloroethane reacts with NaOH(aq). Chlorobenzene does not.

(i) Name the mechanism of the reaction that chloroethane undergoes with NaOH(aq), and identify the major organic product that is formed.

mechanism

major organic product [1]

(ii) Explain the difference in reactivity of chloroethane and chlorobenzene when treated with NaOH(aq).

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

[Total: 11]





- 8 The amino acid serine, $\text{HOCH}_2\text{CH}(\text{NH}_2)\text{COOH}$, exists in two optically active forms. These optical isomers, isomer **P** and isomer **Q**, are shown in Fig. 8.1.



Fig. 8.1

- (a) Isomer **P** and isomer **Q** have identical physical and chemical properties, with the exception of two specific properties. One of these two properties is their differing effect on plane polarised light.

State the other property by which they differ.

.....
 [1]

- (b) A solution of pure isomer **P** of a particular concentration rotates plane polarised light by 5.0° in a clockwise direction.

Describe how a solution of pure isomer **Q** of the same concentration affects plane polarised light.

.....
 [1]

- (c) State another term, in addition to stereoisomers, optical isomers and non-superimposable mirror images, which can be used to describe this pair of chiral compounds, isomer **P** and isomer **Q**.

..... [1]

- (d) Give the term used to describe a mixture containing equal amounts of isomer **P** and isomer **Q**.

..... [1]

- (e) Describe **one** way in which a single pure optical isomer of serine can be produced, instead of making a mixture of isomer **P** and isomer **Q**.

..... [1]



- (f) Complete Table 8.1 to describe the peaks seen in the proton (^1H) NMR spectrum of $\text{HOCH}_2\text{CH}(\text{NH}_2)\text{COOH}$ dissolved in D_2O .

Use as many rows in Table 8.1 as you need to, leaving the other rows blank.

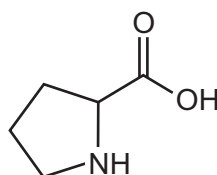
Table 8.1

group responsible for peak	name of splitting pattern shown by peak	explanation for splitting pattern

[3]

- (g) Proline is a naturally occurring amino acid. The skeletal formula of proline is shown.

proline



State the number of peaks in the carbon-13 (^{13}C) NMR spectrum of proline.

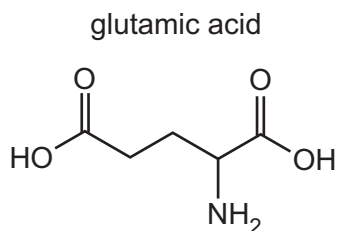
..... [1]





(h) Glutamic acid is a naturally occurring amino acid.

The skeletal formula of glutamic acid is shown.



The isoelectric point of glutamic acid is pH 3.

A sample of glutamic acid is dissolved in a solution of pH 1. A strong alkali is then added until the pH of the mixture reaches pH 14. During this process **all** possible ionised forms of glutamic acid are present at different times, depending on the pH of the solution.

Complete the boxes below to show four **different** ionised forms of glutamic acid that are present at the stated pH values.

at pH 1

at pH 3

at pH 9

at pH 14

[3]

[Total: 12]





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Important values, constants and standards

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



Group																													
1	2	Key													13	14	15	16	17	18									
		atomic number atomic symbol name relative atomic mass						1	H	hydrogen	1.0																		
3	Li	Be																5	B	C	N	O	F	He					
lithium	6.9	beryllium																boron	10.8	carbon	12.0	nitrogen	14.0	oxygen	16.0	fluorine	19.0	helium	4.0
11	Na	Mg																13	Al	Si	P	S	Cl	Ar					
sodium	23.0	magnesium																aluminium	27.0	silicon	28.1	phosphorus	31.0	sulfur	32.1	chlorine	35.5	argon	39.9
19	K	Ca	3	4	5	6	7	8	9	10	11	12							31	Ga	Ge	As	Se	Br	Kr				
potassium	39.1	calcium	scandium	titanium	vanadium	chromium	manganese	iron	cobalt	nickel	copper	zinc							gallium	germanium	arsenic	selenium	bromine	krypton					
37	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd							In	Sn	Sb	Te	I	Xe					
rubidium	85.5	strontium	yttrium	zirconium	niobium	molybdenum	technetium	ruthenium	rhodium	palladium	silver	cadmium							indium	tin	antimony	tellurium	iodine	xenon					
55	Cs	Ba	lanthanoids	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg							Tl	Pb	Bi	Po	At	Rn					
caesium	132.9	barium		hafnium	tantalum	tungsten	rhenium	osmium	iridium	platinum	gold	mercury							thallium	lead	bismuth	polonium	astatine	radon					
87	Fr	Ra	actinoids	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn							Nh	Fl	Mc	Lv	Ts	Og					
				rutherfordium	dubnium	seaborgium	bohrium	hassium	meitnerium	darmstadtium	roentgenium	copernicium							nihonium	flerovium	moscovium	livemorfium	tennessine	oganesson					

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	euroium	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	208.9
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	—

89	Th	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	



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CHEMISTRY

9701/43

Paper 4 A Level Structured Questions

October/November 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) Disodium phosphate, $(\text{Na}^+)_2(\text{HPO}_4^{2-})$, reacts with an acid to form monosodium phosphate, $\text{Na}^+(\text{H}_2\text{PO}_4^-)$.

- (i) Identify the ions that are a conjugate acid–base pair in this reaction, using the formulae of the species involved.

conjugate acid

conjugate base

..... [1]

- (ii) Define buffer solution.

..... [2]

- (iii) Write **two** equations to show how a mixture of $(\text{Na}^+)_2(\text{HPO}_4^{2-})$ and $\text{Na}^+(\text{H}_2\text{PO}_4^-)$ can act as a buffer solution.

equation 1

equation 2 [2]

- (iv) Identify **one** inorganic ion that acts as a buffer in blood.

..... [1]

- (b) Compound **E** is the hydroxide of a Group 2 element. Compound **E** is a strong alkali.

2.63 g of **E** is dissolved in water to make 250 cm^3 of solution **F**. Solution **F** has a pH of 13.09 at 298 K.

- (i) Show that the concentration of hydroxide ions in solution **F** is 0.123 mol dm^{-3} .

[2]

- (ii) Explain why the concentration of compound **E** in solution **F** is $0.0615\text{ mol dm}^{-3}$.

..... [1]

- (iii) Use the concentration given in (ii) to identify compound **E**.

compound **E** [1]





- (c) Compound **E** is much more soluble than magnesium hydroxide.

A saturated solution of magnesium hydroxide in water has a concentration of $1.40 \times 10^{-4} \text{ mol dm}^{-3}$ at 298 K.

Calculate the solubility product, K_{sp} , of magnesium hydroxide. Include units.

$$K_{\text{sp}} = \dots\dots\dots \text{units} \dots\dots\dots [3]$$

- (d) Explain why compound **E** is much more soluble than magnesium hydroxide.

.....

.....

.....

.....

.....

.....

.....

..... [3]

[Total: 16]





- 2 (a) Predict and explain the variation in enthalpy change of hydration for the ions F^- , Cl^- , Br^- and I^- .

.....

 [2]

- (b) Fig. 2.1 shows an incomplete energy cycle involving calcium fluoride, CaF_2 .

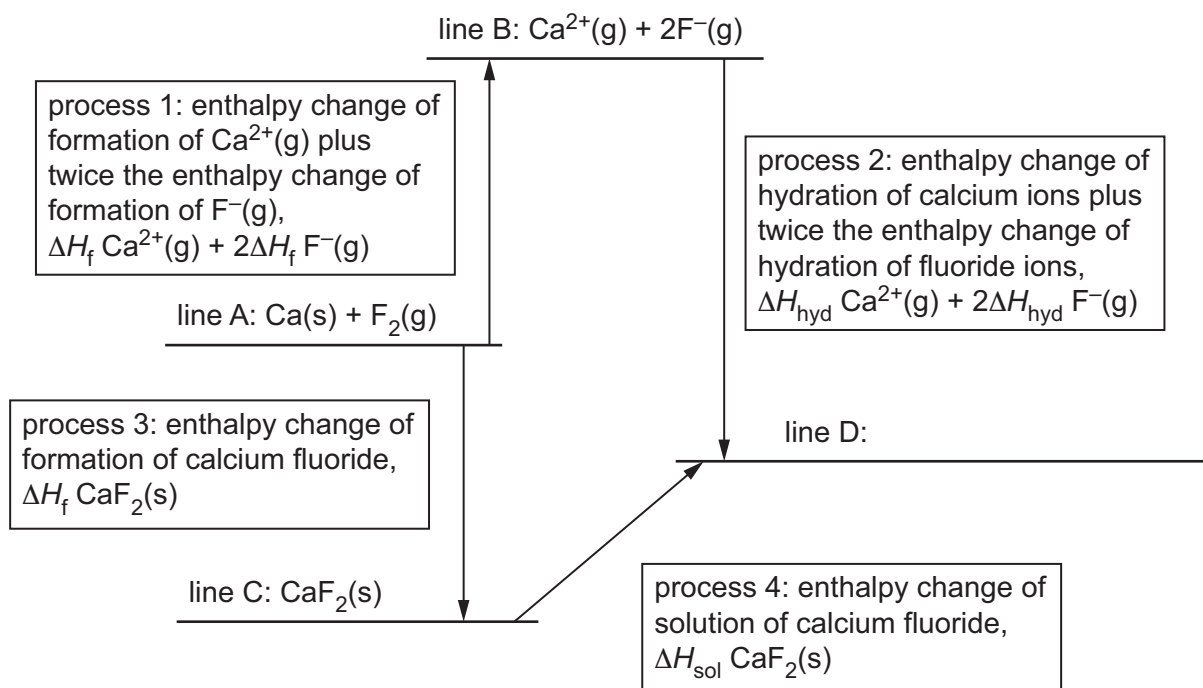
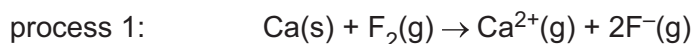


Fig. 2.1

- (i) Complete line D. Include state symbols. [1]
- (ii) The value of the enthalpy change for process 1 can be calculated using the values of **five** other enthalpy changes which are **not** referred to in Fig. 2.1.



Identify these **five** other enthalpy changes, using either names or symbols.

.....

 [2]





(iii) Define lattice energy, ΔH_{latt} .

.....

 [2]

(iv) Complete the expression to give the mathematical relationship between ΔH_{latt} of calcium fluoride and the enthalpy changes for processes 1 and 3.

$$\Delta H_{\text{latt}} =$$

[1]

(c) Use data from Table 2.1 to calculate a value for the hydration energy, ΔH_{hyd} , of fluoride ions, $\text{F}^-(\text{g})$.

Table 2.1

	value / kJ mol^{-1}
enthalpy change of solution of calcium fluoride, $\text{CaF}_2(\text{s})$	+13
overall enthalpy change of process 1 in Fig. 2.1	+1395
enthalpy change of formation of calcium fluoride	−1214
enthalpy change of hydration of $\text{Ca}^{2+}(\text{g})$	−1650

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

(d) Define entropy.

.....
 [1]





(e) At 298 K, the Gibbs free energy change, ΔG , for the solution of compound **T** is $+6.00 \text{ kJ mol}^{-1}$.

The enthalpy change of solution, ΔH_{sol} , of compound **T** is $+30.0 \text{ kJ mol}^{-1}$ at 298 K.

Calculate the value of the entropy change, ΔS , for the solution of compound **T** at 298 K.

$$\Delta S = \dots\dots\dots \text{ J K}^{-1} \text{ mol}^{-1} \quad [2]$$

(f) Predict whether compound **T** becomes more or less soluble as the water is heated from 298 K to 360 K. Explain your answer.

.....

..... [1]

[Total: 14]





- 3 (a) A and B react together to give product AB.



When the concentrations of A and B are both $0.0100 \text{ mol dm}^{-3}$, the rate of formation of AB is $7.62 \times 10^{-4} \text{ mol dm}^{-3} \text{ s}^{-1}$. When the concentrations of A and B are both $0.0200 \text{ mol dm}^{-3}$, the rate of formation of AB is $3.05 \times 10^{-3} \text{ mol dm}^{-3} \text{ s}^{-1}$.

- (i) Complete the **three** possible rate equations that are consistent with these data.

rate = ...

rate = ...

rate = ...

[2]

- (ii) Choose **one** of the rate equations you have written in (i), and calculate the value of the rate constant, k . Include the units of k .

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

- (iii) Explain why it is **not** possible to calculate a value for the half-life, $t_{\frac{1}{2}}$, of this reaction using the value of the rate constant k calculated in (ii) and the equation $k = 0.693/t_{\frac{1}{2}}$.

.....

.....

..... [1]





(b) Catalysts may be homogeneous or heterogeneous.

- (i) Identify **two** metals that act as heterogeneous catalysts in the removal of NO_2 from the exhaust gases of car engines.

..... and [1]

- (ii) Iron acts as a heterogeneous catalyst in the Haber process.

Describe the mode of action of this iron catalyst.

.....

 [2]

- (iii) Fe^{2+} ions act as a homogeneous catalyst in the reaction between $\text{I}^-(\text{aq})$ and $\text{S}_2\text{O}_8^{2-}(\text{aq})$.

Write equations for the **two** reactions that occur when $\text{Fe}^{2+}(\text{aq})$ is added to a mixture of $\text{I}^-(\text{aq})$ and $\text{S}_2\text{O}_8^{2-}(\text{aq})$.

equation 1 $\text{S}_2\text{O}_8^{2-} + \dots\dots\dots$

equation 2 $\dots\dots\dots$ [2]

- (iv) Explain the difference between a homogeneous catalyst and a heterogeneous catalyst.

.....

 [1]

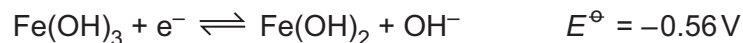


(c) Fe^{2+} ions can be oxidised to Fe^{3+} ions under alkaline conditions by suitable oxidising agents.

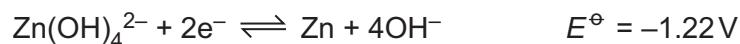
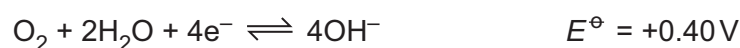
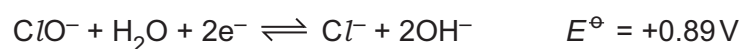
- (i) Iron is a transition element. Explain why iron forms stable compounds in both the +2 and the +3 oxidation states.

..... [1]

- (ii) The half-equation for the reduction of Fe^{3+} under alkaline conditions, and its $E^\ominus$ value, are shown.



Four more half-equations for reactions under alkaline conditions, and their $E^\ominus$ values, are shown.



Select **two** oxidising agents that can oxidise Fe^{2+} ions to Fe^{3+} ions under alkaline conditions.

Write an equation, and give the $E^\ominus_{\text{cell}}$ value, for **each** of the **two** reactions that occur.

oxidising agent 1:

equation:

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

oxidising agent 2:

equation:

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

[4]

[Total: 16]





4 Transition metal atoms and transition metal ions form complexes by combining with ligands.

(a) Explain why transition elements form complex ions.

.....
 [1]

(b) Co^{2+} ions form complex ion **G**.

Each **G** ion contains **two** Co^{2+} ions, both of which are octahedrally coordinated.

Each **G** ion contains one O_2 molecule, which donates one pair of electrons to **each** Co^{2+} ion, and one NH_2^- ion, which donates one pair of electrons to **each** Co^{2+} ion.

The remaining ligands are NH_3 molecules.

(i) Deduce the formula of complex ion **G**. Include its overall charge.

formula of **G** [2]

(ii) The d-orbitals of the Co^{2+} ions present in complex ion **G** are split. State the number of d-orbitals that are at a higher energy level and the number of d-orbitals that are at a lower energy level in **each** Co^{2+} ion.

number of d-orbitals at a higher energy level	
number of d-orbitals at a lower energy level	

[1]

(iii) Co^{2+} ions form a different complex ion, **M**.

Each **M** ion contains **two** Co^{2+} ions, both of which are octahedrally coordinated, but the ligands are different from the ligands in **G**.

Explain why **G** and **M** have different colours.

.....

 [2]



- (c) Cadmium forms complex ion **X**, $[\text{Cd}(\text{NH}_3)_4]^{2+}$.

When a solution containing CN^- ions is added to an aqueous solution of **X**, a ligand exchange reaction takes place, forming complex ion **Y**. **Y** contains no NH_3 ligands and no H_2O ligands.

Y is in a much higher concentration in the mixture than **X**.

The oxidation state and coordination number of cadmium do **not** change in this reaction.

- (i) Write an ionic equation for this reaction, using the formulae of the complex ions.

..... [2]

- (ii) Cadmium forms complex ion **Z** in the same oxidation state and with the same coordination number as in **X**. All the ligands in **Z** are Cl^- ions.

When $\text{NaCl}(\text{aq})$ is added to a solution of **X**, very little **Z** forms.

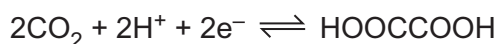
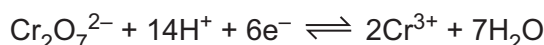
Write the **three** cadmium complexes, **X**, **Y** and **Z**, in order of increasing stability constant, K_{stab} .

.....
smallest value of K_{stab} largest value of K_{stab} [1]

- (d) Ethanedioate ions, $\text{C}_2\text{O}_4^{2-}$, form complexes with transition element ions.

The concentration of $\text{C}_2\text{O}_4^{2-}$ ions can be found by reaction with acidified $\text{Cr}_2\text{O}_7^{2-}$ ions. $\text{C}_2\text{O}_4^{2-}$ ions are protonated and form HOOCCOOH molecules which are oxidised by $\text{Cr}_2\text{O}_7^{2-}$.

The half-equations are shown.



- (i) Construct an equation for the reaction between acidified $\text{Cr}_2\text{O}_7^{2-}$ and HOOCCOOH .

..... [1]

- (ii) A 25.0 cm^3 sample of a solution of $\text{Na}_2\text{C}_2\text{O}_4$ reacts with exactly 16.20 cm^3 of an acidified solution of $0.0500\text{ mol dm}^{-3}$ $\text{K}_2\text{Cr}_2\text{O}_7$.

Calculate the concentration of the solution of $\text{Na}_2\text{C}_2\text{O}_4$.

$[\text{Na}_2\text{C}_2\text{O}_4] = \dots\dots\dots \text{mol dm}^{-3}$ [2]

[Total: 12]





- 5 The shapes of four different complexes, **P**, **Q**, **R** and **S**, are shown in Table 5.1.

The symbol **J** represents an atom or ion of a transition element.

The symbol **L** is used to represent a monodentate ligand.

Table 5.1

P	Q
R	S

- (a) Label **one** bond angle on **each** of complexes **P**, **Q**, **R** and **S**, and identify the size of the angle in degrees. [2]

- (b) Identify the shapes of complexes **P**, **Q**, **R** and **S**.

P

Q

R

S [2]

- (c) Two **L** ligands are exchanged with two **different** monodentate ligands **X** and **Y** in each of complexes **P**, **Q**, **R** and **S**.

Identify all the complexes which form new complexes that show geometrical isomerism.

..... [1]

- (d) Three **L** ligands are exchanged with three **different** monodentate ligands **X**, **Y** and **Z** in each of complexes **P**, **Q** and **R**.

Identify all the complexes which form new complexes that show optical isomerism.

..... [1]

[Total: 6]





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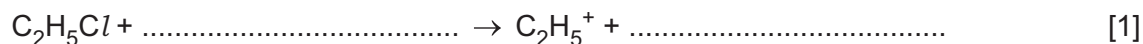
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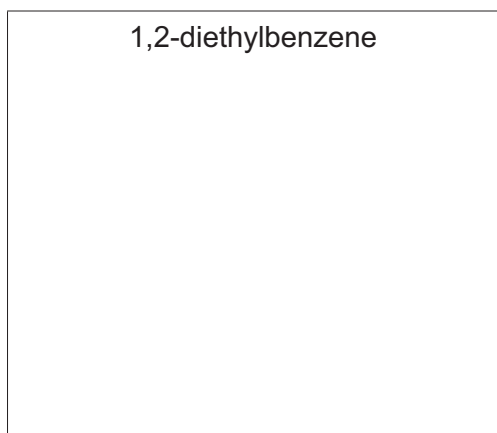
- 6 Benzene, C_6H_6 , reacts with chloroethane, C_2H_5Cl , in the presence of a suitable catalyst to form ethylbenzene, $C_6H_5C_2H_5$. In the presence of the catalyst, the ion $C_2H_5^+$ is formed. This ion reacts with benzene.

- (a) Complete the equation for the reaction of C_2H_5Cl with this catalyst to form $C_2H_5^+$ as one product.



- (b) Ethylbenzene reacts with more C_2H_5Cl , forming a mixture containing 1,2-diethylbenzene and 1,4-diethylbenzene.

- (i) Draw the structures of 1,2-diethylbenzene and 1,4-diethylbenzene.



[1]

- (ii) Explain why there is very little 1,3-diethylbenzene in the product mixture.

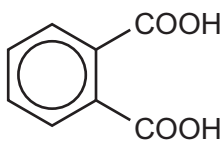
.....

..... [1]



(c) 1,2-diethylbenzene can be oxidised to benzene-1,2-dioic acid, $\text{C}_6\text{H}_4(\text{COOH})_2$.

benzene-1,2-dioic acid



(i) State the reagent and conditions used for this reaction.

..... [1]

(ii) Complete the overall equation for this reaction.

An atom of oxygen from the oxidising agent is represented as [O].

All of the atoms in the two ethyl groups are fully oxidised in this reaction.

..... + ... [O] $\rightarrow$ $\text{C}_6\text{H}_4(\text{COOH})_2$ + ... + ...
(1,2-diethylbenzene) [2]

(iii) Predict the number of peaks in the carbon-13 NMR spectrum of benzene-1,2-dioic acid.

..... [1]





- (d) The proton (^1H) NMR spectra of ethylbenzene, $\text{C}_6\text{H}_5\text{C}_2\text{H}_5$, in CDCl_3 and of benzene-1,2-dioic acid, $\text{C}_6\text{H}_4(\text{COOH})_2$, in CDCl_3 are shown. They have **not** been identified.

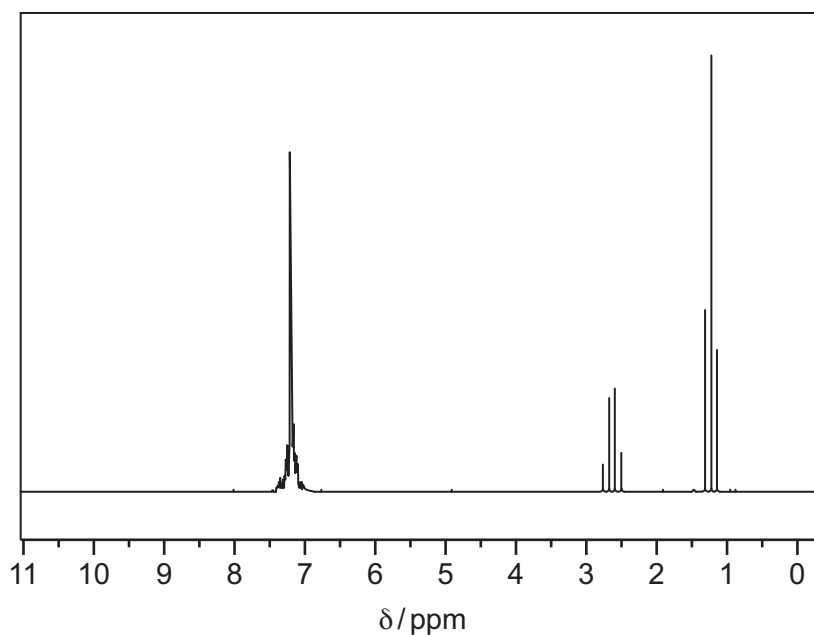


Fig. 6.1

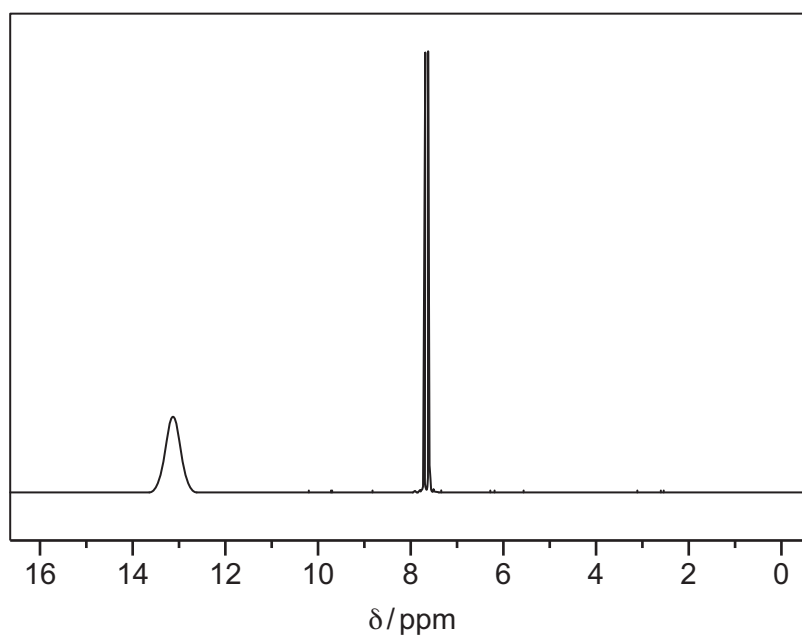


Fig. 6.2

- (i) Explain the use of CDCl_3 , instead of CHCl_3 , as the solvent when obtaining these spectra.

..... [1]



- (ii) Identify the substance shown by the spectrum in Fig. 6.1, and complete Table 6.1.

substance

Table 6.1

	peak at $\delta = 1.2$	peak at $\delta = 2.6$
name of splitting pattern		
group responsible for peak		
explanation of splitting pattern		

[3]

- (iii) Identify the substance shown by the spectrum in Fig. 6.2, and complete Table 6.2.

substance

Table 6.2

	peak at $\delta = 7.8$	peak at $\delta = 13.1$
group responsible for peak		

[1]

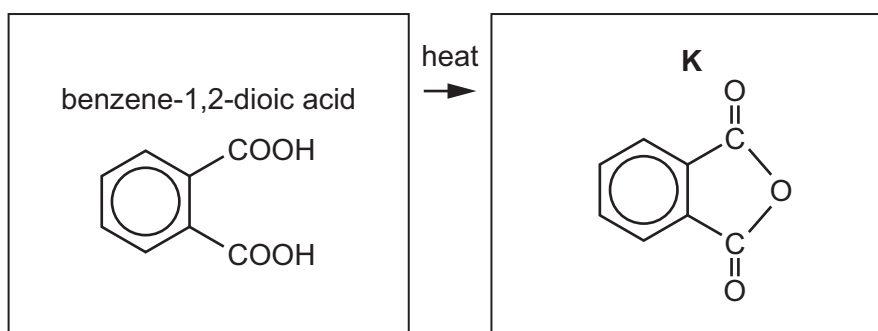
- (iv) When D_2O is used as a solvent, the spectrum obtained is different from the spectrum in Fig. 6.2.

Describe this difference and explain your answer.

.....

 [1]

- (e) Benzene-1,2-dioic acid can be used to produce **K**.



Suggest the name of this type of reaction.

..... [1]





7 A reaction scheme is shown in Fig. 7.1.

The reagents needed for reaction 2 and reaction 3 are stated.

Reaction 5 takes place when $\text{C}_2\text{H}_5\text{NH}_2$ is mixed with compound **V**. No special conditions are required.

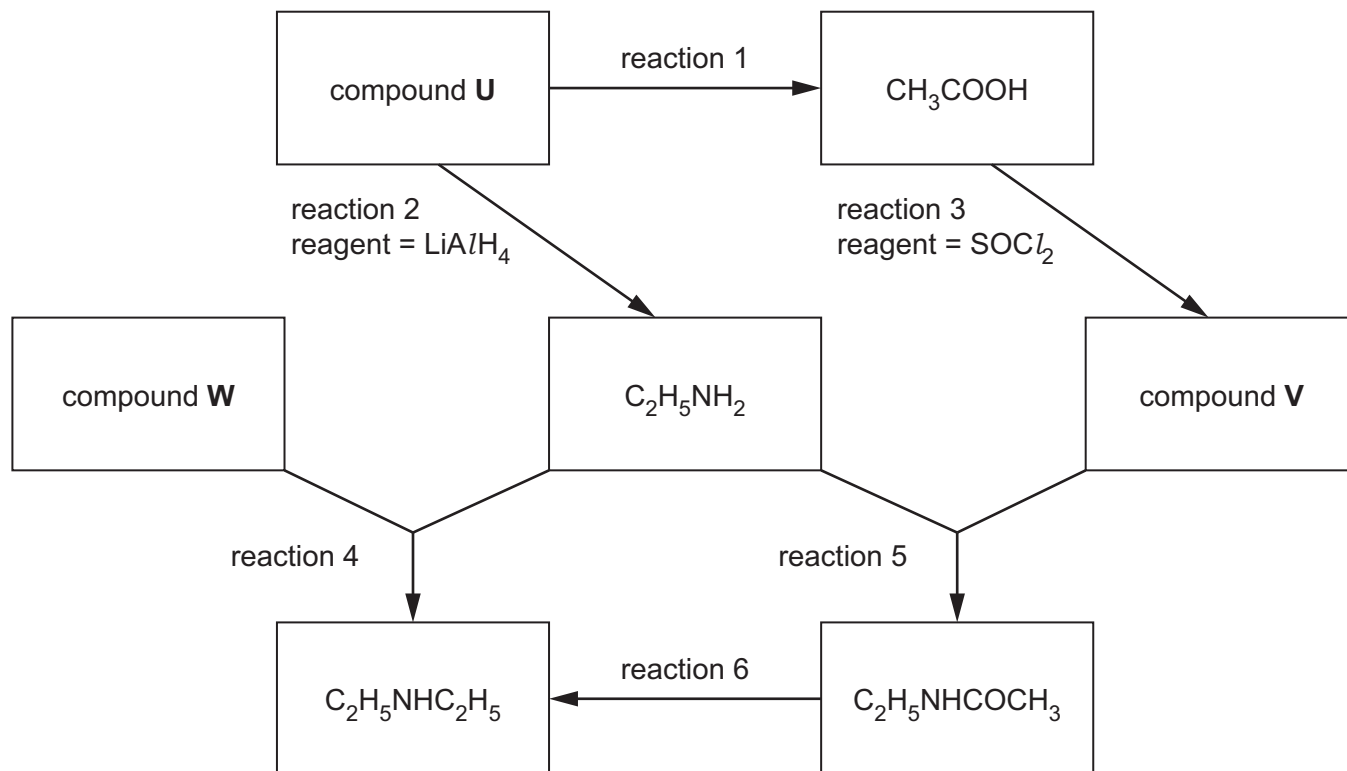


Fig. 7.1

(a) Identify compound **U** which contains only three elements.

..... [1]

(b) Describe the reagents and conditions for reaction 1.

..... [1]

(c) Identify compound **V**.

..... [1]

(d) Complete the equation for reaction 3.

$\text{CH}_3\text{COOH} + \text{SOCl}_2 \rightarrow$ [1]

(e) Identify compound **W**.

..... [1]

(f) Describe the conditions for reaction 4.

..... [1]





- (g) Suggest the reagent needed for reaction 6.

..... [1]

- (h) Complete Table 7.1 by adding the reaction numbers, 1, 2, 3, 4, 5 and 6, to the right-hand column. Use the reaction numbers given in Fig. 7.1.

Each of the numbers 1, 2, 3, 4, 5 and 6 should be used once only.

Table 7.1

type of reaction	reaction number(s)
hydrolysis	
addition	
reduction	
substitution	

[4]

- (i) Compare the basicities of $\text{C}_2\text{H}_5\text{NHCOCH}_3$, $\text{C}_2\text{H}_5\text{NHC}_2\text{H}_5$ and NH_3 .

Explain your answer.

.....
 most basic least basic

 [4]

[Total: 15]





- 8 (a) An aqueous solution of phenol, $\text{C}_6\text{H}_5\text{OH}$, is acidic at 298 K.

Explain why phenol is more acidic than water.

.....

 [2]

- (b) (i) Name the **two** products formed when phenol reacts with an excess of $\text{Br}_2(\text{aq})$.

..... and [1]

- (ii) Draw the structures of the **two** isomeric organic products, with $M_r = 139$, that are formed when phenol reacts with $\text{HNO}_3(\text{aq})$ at room temperature.



[1]

- (iii) Write the equation for the reaction between phenol, $\text{C}_6\text{H}_5\text{OH}$, and sodium metal.

..... [1]

- (c) Phenol can be produced from phenylamine in a two-step synthesis.



Describe the reagents and conditions needed in each step.

step one:

reagents

conditions

step two:

reagents

conditions

[2]

[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)



Group																							
1	2	Key													13	14	15	16	17	18			
				atomic number atomic symbol name relative atomic mass										1H hydrogen 1.0									
3Li lithium 6.9	4Be beryllium 9.0																			2He helium 4.0			
11Na sodium 23.0	12Mg magnesium 24.3	3Sc scandium 45.0	21Y yttrium 88.9	39Zr zirconium 91.2	40Nb niobium 92.9	41Mo molybdenum 95.9	42Tc technetium —	43Ru ruthenium 101.1	44Rh rhodium 102.9	45Pd palladium 106.4	46Ag silver 107.9	47Cd cadmium 112.4	48In indium 114.8	49Sn tin 118.7	50Sb antimony 121.8	51Te tellurium 127.6	52I iodine 126.9	53Xe xenon 131.3					
55Cs caesium 132.9	56Ba barium 137.3	57–71lanthanoids		72Hf hafnium 178.5	73Ta tantalum 180.9	74W tungsten 183.8	75Re rhenium 186.2	76Os osmium 190.2	77Ir iridium 192.2	78Pt platinum 195.1	79Au gold 197.0	80Hg mercury 200.6	81Tl thallium 204.4	82Pb lead 207.2	83Bi bismuth 209.0	84Po polonium —	85At astatine —	86Rn radon —					
87Fr francium —	88Ra radium —	89–103actinoids	104Rf rutherfordium —	105Db dubnium —	106Sg seaborgium —	107Bh bohrium —	108Hs hassium —	109Mt meitnerium —	110Ds darmstadtium —	111Rg roentgenium —	112Cn copernicium —	113Nh nihonium —	114Fl flerovium —	115Mc moscovium —	116Lv livermorium —	117Ts tennessine —	118Og oganesson —						

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	euroium	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	208.9
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	—

89	Ac	actinium
90	Th	thorium
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