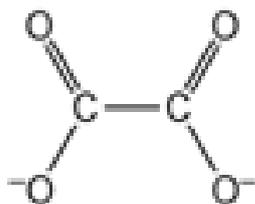


1. This question is about compounds and ions of iron(II) and iron(III) that contain ethanedioate ions, $\text{C}_2\text{O}_4^{2-}$.

The $\text{C}_2\text{O}_4^{2-}$ ion, shown below, is an example of a bidentate ligand.



i. Explain what is meant by the term **bidentate ligand**.

[2]

ii. A complex ion **E** contains three $\text{C}_2\text{O}_4^{2-}$ ions bonded to an iron(III) ion in an octahedral shape.

Complex ion **E** exists as a mixture of two optical isomers.

Draw 3D diagrams to show the structures of the optical isomers of **E**.

Include any overall charge.

[3]

2. This question is about the analysis of organic compounds.

Compounds **F**, **G**, **H** and **I** are structural isomers.

A student carries out test-tube tests on the compounds.
The student records the observations after carrying out each test.
These are shown in **Table 5.1**.

In **Table 5.1**, 2,4-dinitrophenylhydrazine has been abbreviated to 2,4-DNP.

Table 5.1

Compound	Test			
	2,4-DNP	Acidified dichromate(VI) reflux	Bromine water	Tollens' reagent
F	Orange solution	Green solution	Colourless solution	Colourless solution
G	Orange solution	Green solution	Orange solution	Colourless solution
H	Orange precipitate	Orange solution	Orange solution	Colourless solution
I	Orange precipitate	Green solution	Orange solution	Silver mirror

i. Write the formula of the species causing the colours after refluxing with acidified dichromate(VI).

Green solution _____

Orange solution _____

[2]

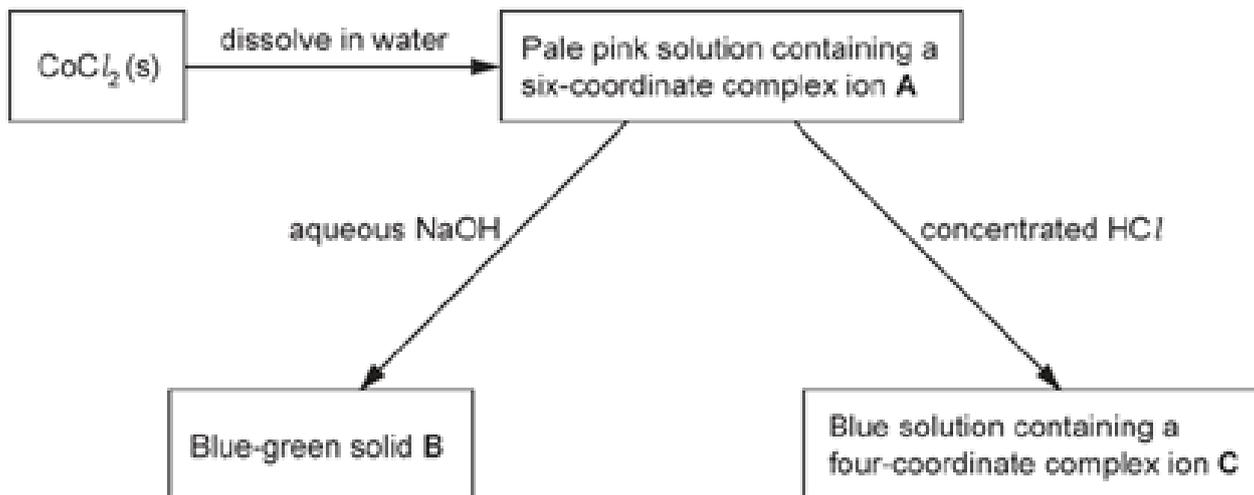
ii. The student is provided with further information about compounds **F–I**.

- They all have the molecular formula $C_5H_{10}O$.
- One of the compounds is alicyclic.
- The other compounds are unbranched.

Use this further information and the student's observations in **Table 5.1** to answer the following.

- How do the observations provide evidence for the possible functional groups in compounds **F–I**?
- Suggest a possible structure for each of the compounds **F–I**.

Show your reasoning.



In **A**, **B** and **C**, cobalt has an oxidation number of +2.

- i. Suggest the formulae of **A**, **B** and **C**.

Complex ion **A**:

Solid **B**:

Complex ion **C**:

[3]

- ii. Cobalt (III) forms an octahedral complex ion **D**, which contains both ammonia and chloride ligands.

Complex ion **D** has a molar mass of 197.9 g mol^{-1} .

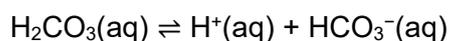
Determine the formula **and** charge of complex ion **D**.

.....
[2]

(c). Red blood cells contain haemoglobin which transports oxygen around the body.

For efficient transportation of oxygen, healthy human blood must be maintained at a pH value between 7.35 and 7.45.

Human blood acts as a buffer due to the presence of carbonic acid, H_2CO_3 , and hydrogencarbonate, HCO_3^- , ions as shown below.



$$K_a = 4.27 \times 10^{-7} \text{ mol dm}^{-3}$$

5. Chlorine has the electron configuration $[\text{Ne}]3s^23p^5$.

Which statement(s) about chlorine is/are correct when it reacts in redox reactions?

- 1 It can gain one electron to form $1-$ ions.
- 2 It can lose its $3s^2$ electrons to form $2+$ ions.
- 3 It can lose its $3p^5$ electrons to form $5+$ ions.

- A 1, 2 and 3
- B Only 1 and 2
- C Only 2 and 3
- D Only 1

Your answer

[1]

6. Which statement(s) about elements in the periodic table is/are correct?

- 1 The position of an element is determined by its relative atomic mass.
- 2 The elements in a group have similar chemical properties.
- 3 Transition elements are used as catalysts in the manufacture of chemicals.

- A 1, 2 and 3
- B Only 1 and 2
- C Only 2 and 3
- D Only 1

Your answer

[1]

7(a). This question is about energy changes.

Hydrogen peroxide decomposes as shown in **Reaction 16.1**.



Reaction 16.1

The table shows enthalpy changes of formation and entropies.

	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	$S^\ominus / \text{J K}^{-1} \text{mol}^{-1}$
$\text{H}_2\text{O}_2(\text{l})$	-188	110
$\text{H}_2\text{O}(\text{l})$	-286	70.0
$\text{O}_2(\text{g})$	0	205

- i. Calculate the free-energy change, ΔG , in kJ mol^{-1} , of **Reaction 16.1** at $25\text{ }^\circ\text{C}$.

Give your answer to **3** significant figures.

$$\Delta G = \dots\dots\dots \text{kJ mol}^{-1} \text{ [4]}$$

- ii. The decomposition of hydrogen peroxide shown in **Reaction 16.1** is feasible.

Suggest why **Reaction 16.1** does **not** take place at $25\text{ }^\circ\text{C}$ despite being feasible.

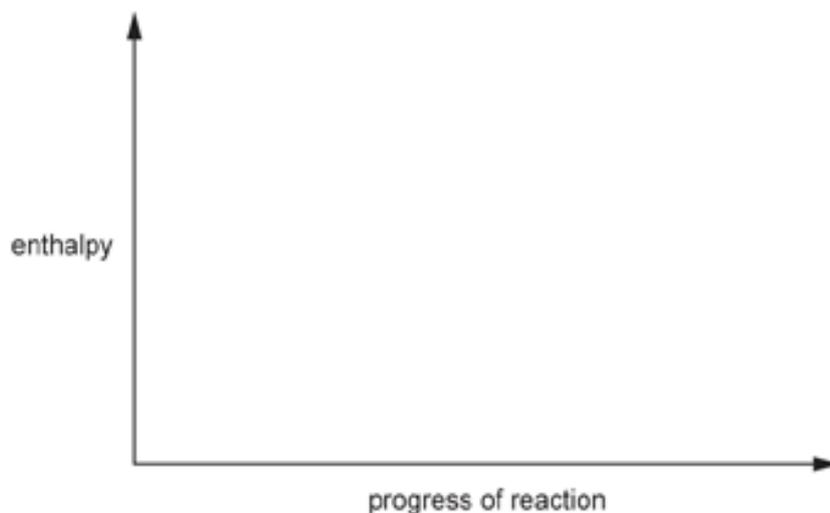
----- [1]

(b). The rate of decomposition of hydrogen peroxide shown in **Reaction 16.1** can be increased by adding a small amount of powdered manganese(IV) oxide, MnO_2 .

The MnO_2 acts as a catalyst.

- i. Complete the enthalpy profile diagram for **Reaction 16.1** using formulae for the reactants and products.

- Use E_a to label the activation energy **without** MnO_2 .
- Use E_c to label the activation energy **with** MnO_2 .
- Use ΔH to label the enthalpy change of reaction.



[3]

- ii. Explain why MnO_2 is described as a **heterogeneous** catalyst for this reaction.

[1]

- iii. Mn_3O_4 is a compound in which Mn has two different oxidation states. The two oxidation states are different from the Mn in MnO_2 .

Suggest the two oxidation states of manganese in Mn_3O_4 .

[1]

8(a). Tutton's salts are 'double salts' with the formula $\text{X}_2\text{Y}(\text{ZO}_4)_2 \cdot 6\text{H}_2\text{O}$.

A Tutton's salt contains two cations: X^+ and Y^{2+} .

- X^+ can be an ion of the Group 1 elements K, Rb, Cs or Fr, or an ammonium ion.
- Y^{2+} can be a 2+ ion of magnesium or an ion of most of the transition elements in Period 4.
- Z can be S or Cr.

$(\text{NH}_4)_2\text{Cu}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$ is an example of a Tutton's salt.

Predict the formula of a Tutton's salt containing different ions from $(\text{NH}_4)_2\text{Cu}(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$.

[1]

(b). The student dissolves their Tutton's salt in water. A pale blue solution forms.

The student carries out two tests on this aqueous solution.

- i. The student adds an excess of aqueous ammonia to their aqueous solution of Tutton's salt. A deep blue solution forms.

The complex ion responsible for the deep blue solution has a molar mass of 167.5 g mol^{-1} .

Suggest the formula of this complex ion.

[1]

[2]

ii. Describe ligand substitution reactions using **either** copper **or** chromium ions as examples.

Include equations.

[2]

(c). The ethanedioate ion, $\text{C}_2\text{O}_4^{2-}$, is a bidentate ligand.

A complex ion of cobalt(III) contains two ethanedioate ligands and two water ligands.

Determine the charge of this complex ion **and** the coordination number of cobalt in the complex ion.

Charge of complex ion

Coordination number of cobalt

[2]

(d). An acidified solution containing $\text{Cr}_2\text{O}_7^{2-}$ ions reacts with vanadium(III) ions in a redox reaction to form a solution containing Cr^{3+} ions and VO_2^+ ions.

Construct the overall equation for this reaction.

[2]

11. Which statement(s) is/are correct for the anti-cancer complex $\text{Pt}(\text{NH}_3)_2\text{Cl}_2$?

- 1 It has bond angles of 90° .
 - 2 The oxidation number of Pt is +4.
 - 3 It forms both optical and *cis-trans* isomers.
- A 1, 2 and 3
B Only 1 and 2
C Only 2 and 3
D Only 1

Your answer

[1]

12(a). This question is about reactions of transition metal compounds.

Ethane-1,2-diamine, $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$, is a bidentate ligand.

The structure of ethane-1,2-diamine is shown below.



- i. Explain why ethane-1,2-diamine can act as a bidentate ligand.

[1]

- ii. The iron(III) ion, Fe^{3+} , forms a complex ion **A** with two ethane-1,2-diamine ligands and two chloride ligands.

Complex ion **A** has *cis* and *trans* stereoisomers.

One of these stereoisomers exists as optical isomers.

Determine the empirical formula, with charge, of complex ion **A** and draw the 3-D structures of the three stereoisomers.

Empirical formula with charge

Structures

[2]

(b). Aqueous sodium hydroxide is added to an aqueous solution of iron(II) sulfate.

A pale green precipitate forms which turns brown when left to stand in air.

- i. Write an ionic equation for the formation of the pale green precipitate.

-----**[1]**

- ii. Use the information below to explain why the pale green precipitate turns brown when left to stand in air and construct an equation for the reaction which occurs.

Redox System	Equation	E°/V
1	$\text{Fe}(\text{OH})_3(\text{s}) + \text{e}^- \rightleftharpoons \text{Fe}(\text{OH})_2(\text{s}) + \text{OH}^-(\text{aq})$	-0.56V
2	$\text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) + 4\text{e}^- \rightleftharpoons 4\text{OH}^-(\text{aq})$	+0.40V

-----**[4]**

(c). * This question is about copper and copper compounds.

Experiment 1

Hydrochloric acid, $\text{HCl}(\text{aq})$, is added to an aqueous solution containing $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ complex ions.

A yellow-green solution forms containing complex ion **B**.

13. Which ion(s) contain(s) one or more unpaired electrons?

- 1 Mn^{3+}
 2 V^{3+}
 3 Cu^+

- A 1, 2 and 3
 B Only 1 and 2
 C Only 2 and 3
 D Only 1

Your answer

[1]

14. Glycine, $\text{H}_2\text{NCH}_2\text{COOH}$, is an α -amino acid.

- i. Glycine reacts with NaOH to form the salt $\text{H}_2\text{NCH}_2\text{COONa}$.

Glycine reacts with HCl to form the salt $\text{HOOCCH}_2\text{NH}_3\text{Cl}$.

The salts have different H-N-H bond angles.

State the different H-N-H bond angles and explain why they are different.

$\text{H}_2\text{NCH}_2\text{COONa}$ H-N-H bond angle = °

$\text{HOOCCH}_2\text{NH}_3\text{Cl}$ H-N-H bond angle = °

explanation _____

-----[3]

- ii. Glycine reacts with aqueous copper(II) ethanoate to form copper(II) glycinate, $\text{Cu}(\text{H}_2\text{NCH}_2\text{COO})_2$, and ethanoic acid. Copper(II) glycinate is a complex which exists as two square planar isomers.

Write an equation for this reaction and draw the structures of the two square planar isomers of the complex $\text{Cu}(\text{H}_2\text{NCH}_2\text{COO})_2$.

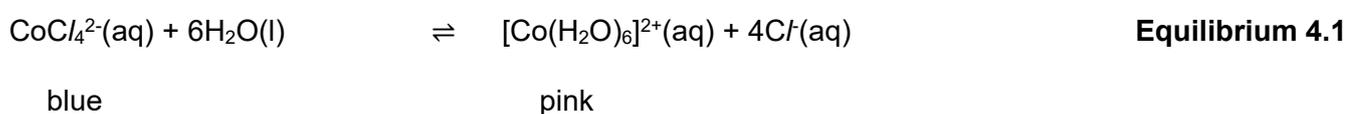
equation _____

structures



[3]

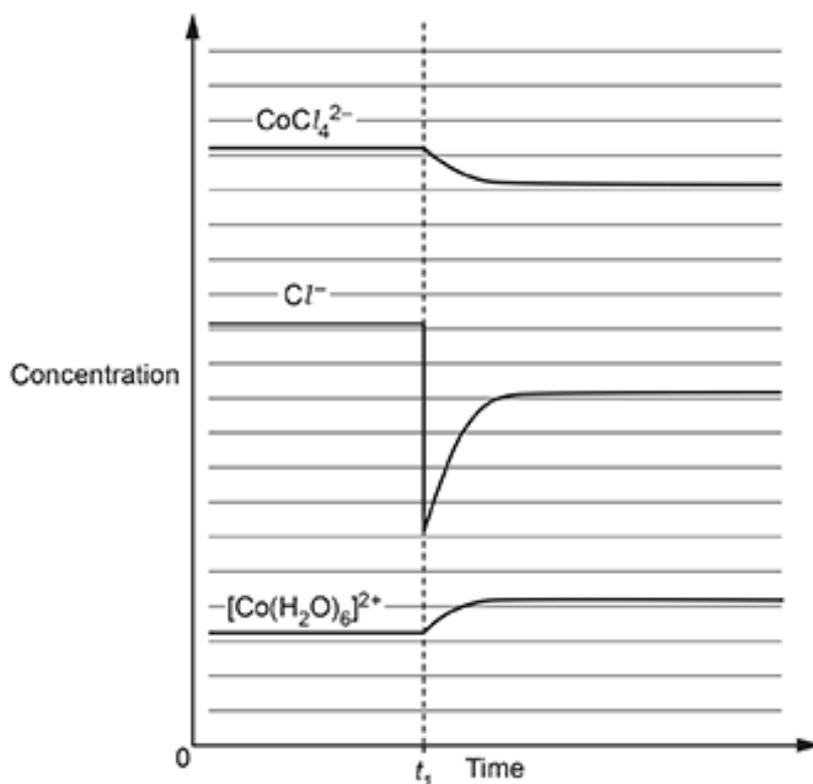
15. Two students plan to investigate **Equilibrium 4.1**, shown below.



The students investigate how addition of aqueous silver nitrate, $\text{AgNO}_3(\text{aq})$, affects the equilibrium position in **Equilibrium 4.1**.

The graph shows the changes in the equilibrium concentrations of CoCl_4^{2-} , Cl^- and $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ after addition of the $\text{AgNO}_3(\text{aq})$.

The $\text{AgNO}_3(\text{aq})$ is added at time = t_1



- i. Explain why the Cl^- concentration drops sharply at time = t_1 .

----- [1]

- ii. Explain the changes in concentration of $CoCl_4^{2-}$, Cl^- and $[Co(H_2O)_6]^{2+}$ after time = t_1 .
Refer to **Equilibrium 4.1** in your answer.

----- [3]

END OF QUESTION PAPER