

- 1 What is the bonding between the ligands and the metal ion in $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$?
- A Metallic
 - B Ionic
 - C Hydrogen
 - D Dative covalent

Your answer

[1]

- 2 Aqueous Cr^{3+} ions are reacted with an excess of aqueous sodium hydroxide.

Which product is formed?

- A** $\text{Cr}(\text{OH})_6^{3-}$
B $\text{Cr}(\text{OH})_3$
C $[\text{Cr}(\text{OH})_4(\text{H}_2\text{O})_2]^-$
D $[\text{Cr}(\text{OH})_4]^{3-}$

Your answer

[1]

3 Which electron configuration(s) is/are correct?

- 1 Cr atom: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^1$
- 2 Cu atom: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$
- 3 Fe^{2+} ion: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^1$

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

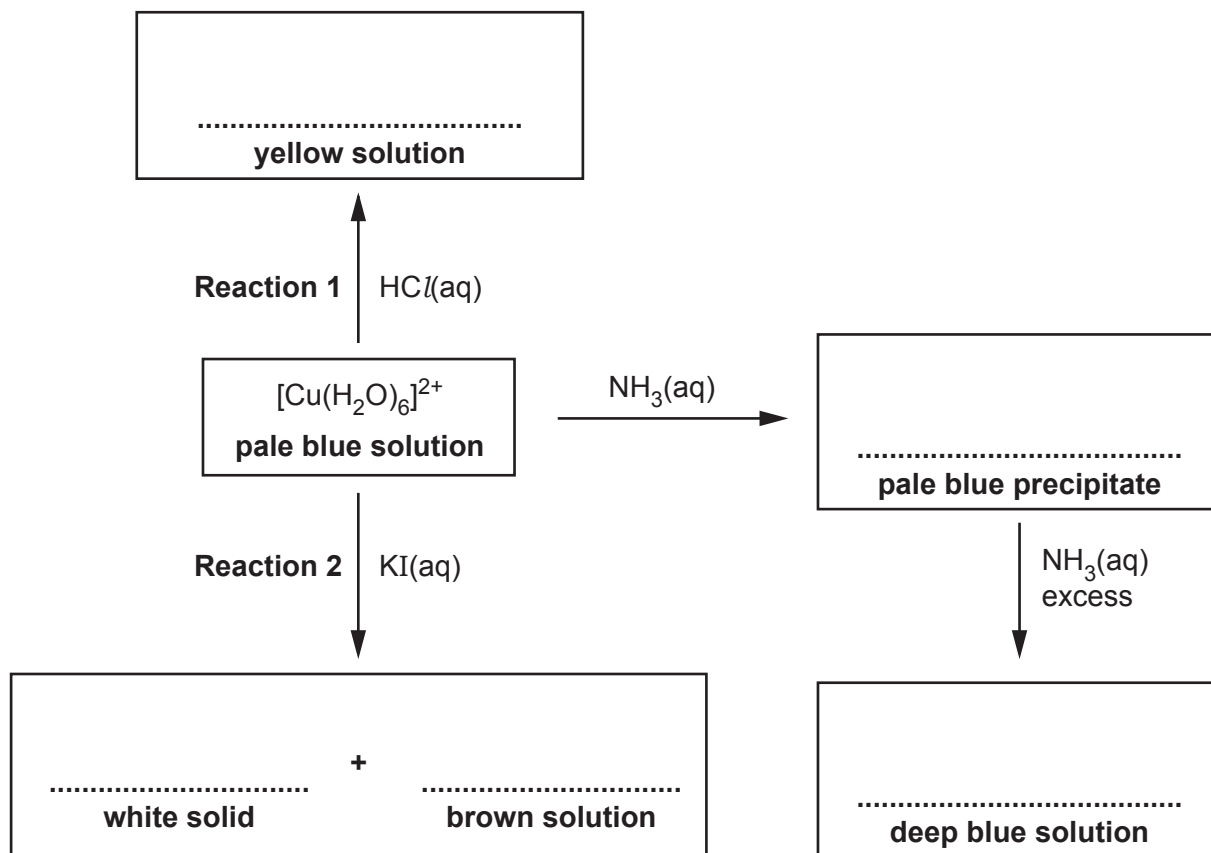
Your answer

[1]

- 4 This question is about reactions of ions and compounds of transition elements.

(a) The flowchart shows reactions of the complex ion $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$.

- (i) In the boxes, write down the formulae of the species responsible for the observations.



[5]

- (ii) Name the type of reaction for **Reaction 1** and **Reaction 2**.

Reaction 1

Reaction 2

[2]

- 5 Which statement(s) is/are correct for the complex $\text{Pt}(\text{NH}_3)_2\text{Cl}_2$?
- 1 One of its stereoisomers is used as an anti-cancer drug.
 - 2 It has bond angles of 109.5° .
 - 3 It has optical isomers.
- A** 1, 2 and 3
- B** Only 1 and 2
- C** Only 2 and 3
- D** Only 1

Your answer

[1]

- 6 This question is about some reactions of d block elements and their ions.

Table 21.1 shows standard electrode potentials which will be needed within this question.

$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^{-}$	$\rightleftharpoons$	$\text{Zn}(\text{s})$	$E^{\circ} = -0.76 \text{ V}$
$\text{Cr}^{3+}(\text{aq}) + \text{e}^{-}$	$\rightleftharpoons$	$\text{Cr}^{2+}(\text{aq})$	$E^{\circ} = -0.42 \text{ V}$
$\text{Ni}^{2+}(\text{aq}) + 2\text{e}^{-}$	$\rightleftharpoons$	$\text{Ni}(\text{s})$	$E^{\circ} = -0.25 \text{ V}$
$\text{I}_2(\text{aq}) + 2\text{e}^{-}$	$\rightleftharpoons$	$2\text{I}^{-}(\text{aq})$	$E^{\circ} = +0.54 \text{ V}$
$\text{Fe}^{3+}(\text{aq}) + \text{e}^{-}$	$\rightleftharpoons$	$\text{Fe}^{2+}(\text{aq})$	$E^{\circ} = +0.77 \text{ V}$
$\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 14\text{H}^{+}(\text{aq}) + 6\text{e}^{-}$	$\rightleftharpoons$	$2\text{Cr}^{3+}(\text{aq}) + 7\text{H}_2\text{O}(\text{l})$	$E^{\circ} = +1.33 \text{ V}$
$\text{H}_2\text{O}_2(\text{aq}) + 2\text{H}^{+}(\text{aq}) + 2\text{e}^{-}$	$\rightleftharpoons$	$2\text{H}_2\text{O}(\text{l})$	$E^{\circ} = +1.78 \text{ V}$

Table 21.1

- (a) Complete the electron configuration of

a Ni atom: 1s^2

a Ni^{2+} ion: 1s^2 [2]

(b)* Three different reactions of copper compounds are described below.

Reaction 1: Aqueous copper(II) sulfate reacts with excess aqueous ammonia in a ligand substitution reaction. A deep-blue solution is formed, containing an octahedral complex ion, **C**, which is a *trans* isomer.

Reaction 2: Copper(I) oxide reacts with hot dilute sulfuric acid in a disproportionation reaction. A blue solution, **D**, and a brown solid, **E** are formed.

Reaction 3: Copper(II) oxide reacts with warm dilute nitric acid in a neutralisation reaction, to form a blue solution. Unreacted copper(II) oxide is filtered off, and the solution is left overnight in an evaporating basin.

A hydrated salt, **F**, crystallises, with the percentage composition by mass:
Cu, 26.29%; H, 2.48%; N, 11.59%; O, 59.63%.

Identify **C–F** by formulae or structures, as appropriate.

Include equations, any changes in oxidation number, and working.

[6]

[illegible]

Additional answer space if required.

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END OF QUESTION PAPER

- 7 What is the number of stereoisomers that $\text{Ni}(\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2)_2\text{Cl}_2$ can form?
- A** 2
- B** 3
- C** 4
- D** 6

Your answer

[1]

8 Which property/properties is/are correct for a transition element?

- 1 The element has atoms with a partially filled d sub-shell.
- 2 The existence of more than one oxidation state in its compounds.
- 3 The formation of coloured ions.

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

Your answer

[1]

9(a) Red blood cells contain haemoglobin.

Explain using ligand substitutions:

- how haemoglobin transports oxygen around the body
- why carbon monoxide is toxic.

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

- 10 This question is about reactions of ions and compounds of transition elements.

(a) A student carries out two experiments on a solution containing $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$.

Experiment 1

The student adds an excess of aqueous ammonia to a solution containing $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$ until a purple solution is formed.

Experiment 2

The student carries out the following reaction sequence.

Step 1 $\text{NaOH}(\text{aq})$ is added slowly to a solution containing $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}(\text{aq})$ in a boiling tube.
A grey-green precipitate forms.

Step 2 An excess of $\text{NaOH}(\text{aq})$ is added to the boiling tube.
The precipitate dissolves and a green solution forms containing a 6 coordinate complex ion.

Step 3 H_2O_2 is added to the mixture and the boiling tube is heated.
A yellow solution forms.

Step 4 The solution in the boiling tube is acidified.
The solution now contains $\text{Cr}_2\text{O}_7^{2-}(\text{aq})$.

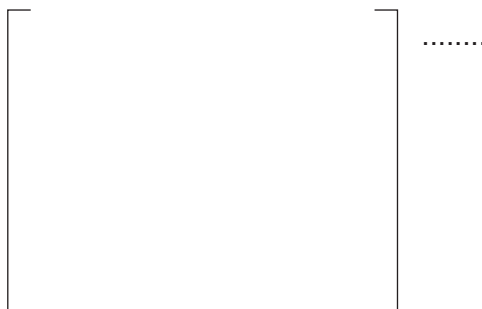
(i) What is the formula of the complex ion in the purple solution that forms in **Experiment 1**?

..... [1]

(ii) Suggest an equation for the reaction in **Experiment 2, Step 1**.
Include state symbols.

..... [1]

(iii) Draw a 3-D diagram for the shape of the complex ion that forms in **Experiment 2, Step 2**.
Include the charge of the ion.



[2]

(iv) What is the formula of the **ion** that causes the yellow colour in **Experiment 2, Step 3**?

..... [1]

(v) State the colour of the solution that forms in **Experiment 2, Step 4**.

- (b) Vanadium ions have four common oxidation states. **Table 18.1** shows the colours of the ions in aqueous solution.

Oxidation state of vanadium	Vanadium ion	Colour
+5	$\text{VO}_2^+(\text{aq})$	yellow
+4	$\text{VO}^{2+}(\text{aq})$	blue
+3	$\text{V}^{3+}(\text{aq})$	green
+2	$\text{V}^{2+}(\text{aq})$	violet

Table 18.1

- (i) Complete the electron configuration of a V^{3+} ion.

$1s^2$ [1]

- (ii) The student adds excess iron to a solution containing $\text{VO}^{2+}(\text{aq})$ ions, and observes that the colour of the solution changes from blue to green and then to violet.

Use the relevant standard electrode potentials shown in **Table 18.2** to explain these observations.

Redox system			E°/V
1	$\text{V}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{V}(\text{s})$		-1.18
2	$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Fe}(\text{s})$		-0.44
3	$\text{V}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{V}^{2+}(\text{aq})$		-0.26
4	$\text{VO}^{2+}(\text{aq}) + 2\text{H}^+ + \text{e}^- \rightleftharpoons \text{V}^{3+}(\text{aq}) + \text{H}_2\text{O}(\text{l})$		+0.34
5	$\text{Fe}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{Fe}^{2+}(\text{aq})$		+0.77
6	$\text{VO}_2^+(\text{aq}) + 2\text{H}^+ + \text{e}^- \rightleftharpoons \text{VO}^{2+}(\text{aq}) + \text{H}_2\text{O}(\text{l})$		+1.00

Table 18.2

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..... [3]

- (iii) Construct an equation for the **first** colour change from blue to green.

11 Which statement(s) for the complex ion $[\text{Co}(\text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2)_3]^{2+}$ is/are correct?

1 It has *cis* and *trans* isomers.

2 It has optical isomers.

3 It is six-fold coordination.

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer

[1]

12 (a)* **B** and **C** are compounds of two different transition elements.

A student carries out test tube reactions on aqueous solutions of **B** and **C**.
The observations of the student's tests are shown below.

	Test	B(aq)	C(aq)
1	NH ₃ (aq) added dropwise	green precipitate D	grey-green precipitate E
	excess NH ₃ (aq) added	no further change	purple solution F
2	HNO ₃ (aq)	no change	no change
	followed by Ba(NO ₃) ₂ (aq)	white precipitate G	no change
3	HNO ₃ (aq)	no change	no change
	followed by AgNO ₃ (aq)	no change	white precipitate H

Analyse the results to identify **B** to **H**, and construct ionic equations for the formation of products **D** to **H**. [6]

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Additional answer space if required

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- (b)** A compound of nickel, **J**, has the formula $(\text{NH}_4)_2[\text{Ni}(\text{SCN})_x(\text{NH}_3)_y]$ and contains SCN^- and NH_3 ligands.

The percentage by mass of three of the elements in compound **J** is shown below:
 Ni, 16.26%; S, 35.56%; N, 31.00%.

- (i)** Calculate the values of x and y in the formula of compound **J**.

$x =$

$y =$

[3]

- (ii)** Determine the oxidation number of nickel in compound **J**.

oxidation number: **[1]**

- 13 $\text{NH}_4\text{Fe}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ is a hydrated 'double salt'.

A student analyses this double salt using test tube tests.

Which row(s) gives/give correct result(s) for the stated test?

	Test	Results
1	Reaction with cold $\text{NaOH}(\text{aq})$	Green precipitate
2	Reaction with $\text{Ba}(\text{NO}_3)_2(\text{aq})$	White precipitate
3	Reaction with warm $\text{NaOH}(\text{aq})$	Red-brown precipitate and an alkaline gas

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

Your answer

[1]

14 This question is about d-block elements.

(a) Most d-block elements are also classified as transition elements.

Explain why scandium and zinc are classified as d-block elements but are **not** also transition elements.

Your explanations should include full electron configurations.

..... [4

(b) Compound **A** is a hydrated chromium(III) salt with a molar mass of 608.3 g mol^{-1} and the following percentage composition by mass:

Cr, 17.10%; H, 3.94%; O, 63.13%; S, 15.83%.

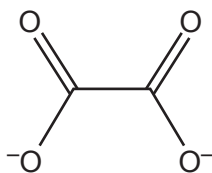
A student dissolves compound **A** in water.

The resulting solution contains the complex ion $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$.

The student mixes this solution with aqueous sodium ethanedioate, $\text{Na}_2\text{C}_2\text{O}_4$.

A ligand substitution reaction takes place forming a solution containing three stereoisomers of a complex ion **B** of chromium(III).

Complex ion **B** is six-coordinate and contains two ethanedioate ligands and two water ligands. The ethanedioate ion is the bidentate ligand shown below.



Ethanedioate ligand

(i) What is meant by a **bidentate ligand**?

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(ii)* Determine the formulae of **A** and **B**. Write the ionic equation for the ligand substitution and show 3D structures for the three stereoisomers of **B**.

[6]

Additional answer space if required.

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- 15** Prussian blue, $\text{C}_{18}\text{Fe}_7\text{N}_{18}$, is a deep blue pigment containing Fe^{2+} , Fe^{3+} and CN^- ions.

What are the numbers of Fe^{2+} and Fe^{3+} ions in one formula unit of $\text{C}_{18}\text{Fe}_7\text{N}_{18}$?

- A** 2 Fe^{2+} and 5 Fe^{3+}
B 3 Fe^{2+} and 4 Fe^{3+}
C 4 Fe^{2+} and 3 Fe^{3+}
D 5 Fe^{2+} and 2 Fe^{3+}

Your answer

[1]

16 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

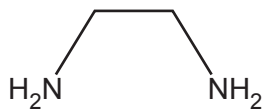
Your answer

[1]

17 This question is about reactions of transition metal compounds.

(a) 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.

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 [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

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

Experiment 1

Hydrochloric acid, HCl(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**.

Experiment 2

A piece of copper metal is heated with concentrated sulfuric acid.

A reaction takes place forming a pale blue solution **C** and 45 cm^3 of a gas **D**, measured at RTP. The mass of gas **D** is 0.12 g.

Experiment 3

An excess of copper(II) oxide is heated with dilute nitric acid. The resulting mixture is filtered. The filtrate is a blue solution **E**.

Aqueous potassium iodide, KI(aq) , is added to the blue solution **E**.

A white precipitate **F** and a brown solution **G** form.

Determine the formulae of **B–G**.

Construct equations for the reactions taking place, include any changes in oxidation number, and show your working where appropriate.

[6]

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Additional answer space if required.

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END OF QUESTION PAPER

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

- 19** This question is about the d-block elements in Period 4 of the periodic table (Sc to Zn).

(a)* Explain, with examples from Period 4, what is meant by the terms **d-block element** and **transition element**.

Explain why some d-block elements are **not** transition elements.

Use electron configurations to support your explanations.

[6]

Additional answer space if required.

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- (b) (i) Describe precipitation reactions using **either** copper **or** chromium ions as examples.

Include equations.

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..... [2]

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

Include equations.

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..... [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.

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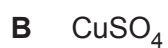
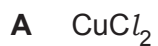
END OF QUESTION PAPER

- 20 A student analyses a solution of a salt.

The results are shown below.

Test	Observation
Reaction with NaOH(aq)	Green precipitate
Reaction with Ba(NO ₃) ₂ (aq)	White precipitate

What is the formula of the salt?



Your answer

[1]

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

22 This question is about transition elements.

(a) Iron is in the d block of the periodic table and contains s, p and d orbitals.

- Draw diagrams to show the shapes of an s orbital and a p orbital.
- Complete the electron configurations of an iron atom and an iron(II) ion.

Shapes

s orbital	p orbital

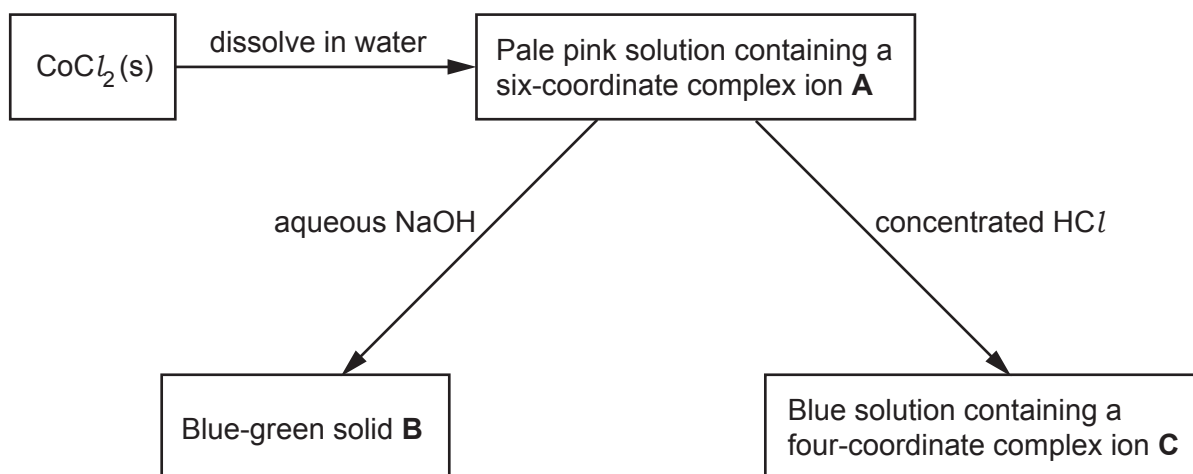
Electron configurations

Iron atom: $1s^2$

Iron(II) ion $1s^2$

[2]

(b) The flowchart shows some reactions of cobalt(II) chloride, CoCl_2 .



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**:

- (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.



- Explain, using ligand substitution, how haemoglobin transports oxygen around the body.
- Determine whether a sample of blood with a $[\text{HCO}_3^-] : [\text{H}_2\text{CO}_3]$ ratio of 8.5:1 is healthy.

..... [5]

- 23** Chromium forms the complex ions $[\text{Cr}(\text{NH}_3)_6]^{3+}$ and $[\text{Cr}(\text{OH})_6]^{3-}$.

Which statement(s) about the complexes is/are correct?

24 This question is about reactions of compounds of iron and copper.

(a)

(i) Complete the electron configuration of

an Fe atom: $1s^2$

a Cu^{2+} ion: $1s^2$

[2]

(ii) Solutions of iron(II) sulfate, FeSO_4 , and copper(II) sulfate, CuSO_4 , can be distinguished by adding aqueous sodium hydroxide.

Describe what would be observed when NaOH(aq) is added to each solution.

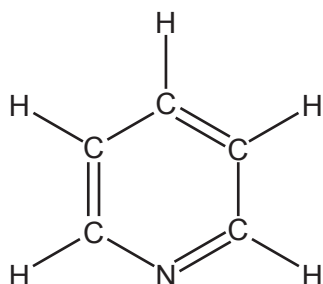
Observation with $\text{FeSO}_4\text{(aq)}$

Observation with $\text{CuSO}_4\text{(aq)}$

[2]

(b) The cyclic organic compound pyridine, $\text{C}_5\text{H}_5\text{N}$, can act as a monodentate ligand.

The structure of pyridine is shown below.



(i) What is meant by a **monodentate ligand**?

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..... [1]

(ii) An iron(II) complex contains two different ligands: $\text{C}_5\text{H}_5\text{N}$, and Cl^- .

The complex has a molar mass of 442.8 g mol^{-1} and the following percentage composition by mass:

Fe, 12.6%; C, 54.3%; H, 4.5%; N, 12.6%; Cl, 16.0%

Determine the empirical formula of the iron(II) complex.

Deduce the number of $\text{C}_5\text{H}_5\text{N}$ ligands in the complex and the coordination number of the iron(II) ion.

Empirical formula of iron(II) complex

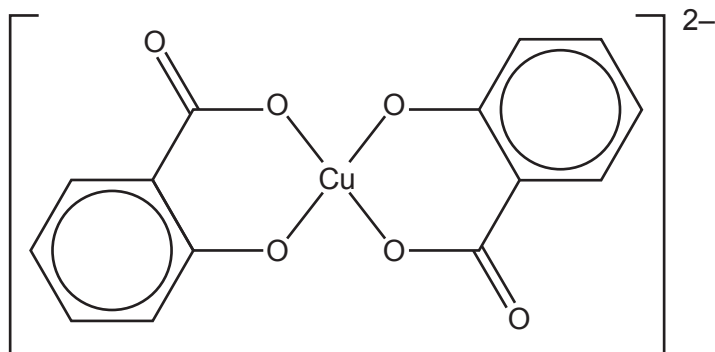
Number of $\text{C}_5\text{H}_5\text{N}$ ligands

Coordination number of iron(II) ion

[4]

- (c) Aqueous copper(II) sulfate reacts with salicylic acid to form a complex ion which has two stereoisomers.

One isomer of the complex ion is shown:



Draw the other stereoisomer of the complex.

Identify the type of stereoisomerism shown by the complexes.

Type of stereoisomerism [2]