

OCR A-LEVEL CHEMISTRY A • H432

CHEMISTRY



EXAM QUESTION PACK

5.3 TRANSITION ELEMENTS

SCORE

/256

PERCENTAGE

%

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- 1(a) The cobalt(III) ion, Co^{3+} , forms a complex ion **A** with two chloride ligands and two ethanediamine, $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$, ligands.

The structure of ethanediamine is shown below.



- (i) Explain how ethanediamine is able to act as a bidentate ligand.

----- [2]

- (ii) Write the formula of complex ion **A**.

----- [1]

- (iii) What is the coordination number of cobalt in complex ion **A**?

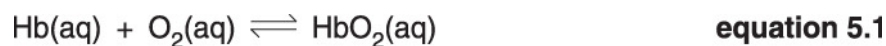
----- [1]

- (iv) Complex ion **A** has *cis* and *trans* stereoisomers. One of these stereoisomers also has an optical isomer.

Draw 3-D diagrams to show the three stereoisomers.

[3]

- (b) The equilibrium reaction for the transport of oxygen by haemoglobin (Hb) in blood can be represented as **equation 5.1**.



- (i) Explain how ligand substitution reactions allow haemoglobin to transport oxygen in blood.

----- [2]

- (ii) Write an expression for the stability constant, K_{stab} , for the equilibrium involved in the transport of oxygen by haemoglobin.

Use the simplified species in **equation 5.1**.

[1]

- (iii) In the presence of carbon monoxide, less oxygen is transported in the blood.

Suggest why, in terms of bond strength and stability constants.

----- [2]

2(a) A student carries out an investigation to prepare and analyse a sample of barium ferrate(VI), BaFeO₄. The steps in the investigation are shown below.

Step 1

The student adds solid iron(III) oxide to a hot aqueous solution containing an excess of hydroxide ions. The student bubbles chlorine gas through the mixture.

A solution forms containing aqueous ferrate(VI) ions, FeO₄²⁻(aq), and aqueous chloride ions.

Step 2

The student adds aqueous barium chloride to the resulting solution.

A precipitate of impure barium ferrate(VI) forms.

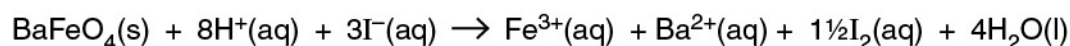
The precipitate is filtered, washed with distilled water and dried.

The student obtains 0.437 g of impure solid barium ferrate(VI).

Step 3

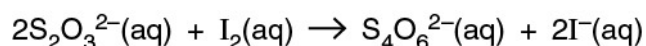
An excess of acidified aqueous potassium iodide is added to the solid from **step 2**.

The BaFeO₄ reacts as shown below, and the impurity does not react. A solution forms containing aqueous iodine, I₂(aq).



Step 4

The student determines the amount of I₂ formed by carrying out a titration with aqueous sodium thiosulfate, Na₂S₂O₃(aq).



26.4 cm³ of 0.100 mol dm⁻³ Na₂S₂O₃(aq) are required to reach the end point.

Construct an equation for the oxidation of iron(III) oxide (**step 1**).

-----[2]

(b) Write an ionic equation for the formation of barium ferrate(VI) (**step 2**).

Include state symbols.

-----[1]

(c) In **step 3**, what is the reducing agent?

Explain your answer in terms of electrons.

reducing agent -----

explanation -----

[2]

(d) The solid sample of barium ferrate(VI) obtained in step 2 is impure.

Determine the percentage, by mass, of barium ferrate(VI) in the 0.437 g of solid formed in **step 2**.

Give your answer to **one** decimal place.

percentage of barium ferrate(VI) = ----- % [4]

- (e) When the solution is not alkaline, ferrate(VI) ions react with water.
The reaction forms a gas with a density of $1.333 \times 10^{-3} \text{ g cm}^{-3}$, measured at room temperature and pressure, and an orange–brown precipitate.

- Determine the formulae of the gas and the precipitate.
- Write an equation for the reaction that takes place.

gas

precipitate

equation

[3]

3(a) Write the equation for a reaction catalysed by a named transition element, compound or ion.

Equation: _____

Catalyst: _____ [1]

(b) An octahedral complex ion **A**, $\text{C}_9\text{H}_{30}\text{N}_6\text{Ni}^{3+}$, exists as two optical isomers.

In complex ion **A**, Ni^{3+} is bonded to three molecules of a bidentate ligand **B**.

(i) State what is meant by a *bidentate ligand*.

----- [1]

(ii) What is the molecular formula of the bidentate ligand **B**?

----- [1]

(iii) Draw a possible structure for **B** and explain how **B** is able to act as a bidentate ligand.

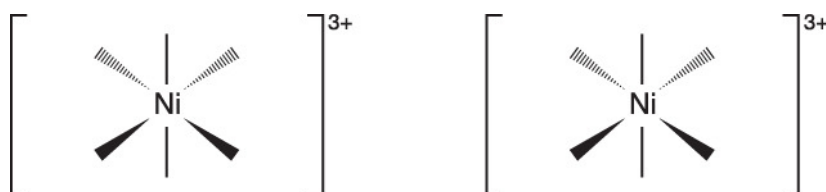
----- [2]

(iv) What is the coordination number of complex ion **A**?

----- [1]

(v) Complete the 3-D diagrams of the shapes of the optical isomers of complex ion **A**.

You can show the bidentate ligand simply as



[1]

(c) Describe the reactions of **EITHER** aqueous copper(II) ions **OR** aqueous cobalt(II) ions with:

- aqueous sodium hydroxide
- excess aqueous ammonia
- hydrochloric acid.



In your answer you should link observations with equations.

[6]

4(a) Some electrode potentials for ions are shown below.

$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^{-}$	$\rightleftharpoons$	$\text{Fe}(\text{s})$	$E^{\circ} = -0.44\text{V}$
$\text{Fe}^{3+}(\text{aq}) + \text{e}^{-}$	$\rightleftharpoons$	$\text{Fe}^{2+}(\text{aq})$	$E^{\circ} = +0.77\text{V}$
$\frac{1}{2}\text{I}_2(\text{aq}) + \text{e}^{-}$	$\rightleftharpoons$	$\text{I}^{-}(\text{aq})$	$E^{\circ} = +0.54\text{V}$
$\frac{1}{2}\text{Br}_2(\text{aq}) + \text{e}^{-}$	$\rightleftharpoons$	$\text{Br}^{-}(\text{aq})$	$E^{\circ} = +1.09\text{V}$
$\frac{1}{2}\text{Cl}_2(\text{aq}) + \text{e}^{-}$	$\rightleftharpoons$	$\text{Cl}^{-}(\text{aq})$	$E^{\circ} = +1.36\text{V}$

(i) Complete the electron configurations for Fe^{2+} and Br^{-} .

Fe^{2+} : 1s^2 _____
 Br^{-} : 1s^2 _____

[2]

(ii) Predict the products of reacting $\text{Fe}(\text{s})$ separately with $\text{I}_2(\text{aq})$, $\text{Br}_2(\text{aq})$ and $\text{Cl}_2(\text{aq})$.

Explain your predictions using the electrode potential data above.

[3]

(b) Fe^{2+} ions can be used to test for NO_3^- ions.

In this test, aqueous iron(II) sulfate is added to a solution containing NO_3^- ions, followed by slow addition of concentrated sulfuric acid. The sulfuric acid forms a layer below the aqueous solution.

In the presence of NO_3^- ions, a brown ring forms between the two layers.

Two reactions take place.

Reaction 1: In the acid conditions Fe^{2+} ions reduce NO_3^- ions to NO.

Fe^{2+} ions are oxidised to Fe^{3+} ions.

Water also forms.

Reaction 2: A ligand substitution reaction of $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$ takes place in which one NO ligand exchanges with one water ligand. A deep brown complex ion forms as the brown ring.

Construct equations for these two reactions.

Reaction 1:

Reaction 2:

----- [3]

5 Copper(II) ions form an aqueous complex ion, X, with chloride ions.

Which statement about X is true?

- A X has optical isomers
- B X has a square planar shape
- C X has the formula CuCl_4^{2+}
- D X has a yellow colour

Your answer

☐

[1]

6 Two tests are carried out on an aqueous solution of copper(II) sulfate, $\text{CuSO}_4(\text{aq})$.

Test 1: Addition of potassium iodide solution

Test 2: Addition of barium chloride solution

Which of the following statements is / are true?

1: **Test 1** produces an off-white precipitate and a brown solution.

2: **Test 2** produces a white precipitate.

3: **Test 1** and **Test 2** are both redox reactions.

A 1, 2 and 3

B Only 1 and 2

C Only 2 and 3

D Only 1

Your answer

☐

[1]

7(a) A student carries out a number of experiments on transition metal compounds.

4.800 g of a green hydrated crystalline solid **A** are heated in a crucible to remove the water of crystallisation.

1.944 g of water are removed to leave 0.0180 mol of solid residue **B**.

Solid **B** contains 32.8%, by mass, of the transition metal.

All of **B** is reacted with $\text{AgNO}_3(\text{aq})$ to form 7.695 g of a white precipitate, **C**.

The green crystalline solid **A** is dissolved in water to produce a green solution containing a complex ion, **D**.

When aqueous sodium hydroxide is added to solution of **D**, a grey-green precipitate, **E**, is observed, which dissolves in excess aqueous sodium hydroxide to form a green solution.

Determine the formulae of **A**, **B**, **D** and **E**.

Show **all** your working.

A = _____

D = _____

B = _____

C = _____

[9]

Describe the different shapes and the different types of stereoisomerism found in transition metal chemistry.

Use suitable examples and diagrams in your answer.

[6]

8(a) This question is about the chemistry of transition elements.

Many chromium compounds contain chromium in the +3 oxidation state.

Complete the electron configurations of chromium as the element and in the +3 oxidation state.

Chromium as the element: $1s^2 2s^2 2p^6$ _____

Chromium in the +3 oxidation state: $1s^2 2s^2 2p^6$ _____

[2]

(b) Compound I is a complex with the empirical formula $\text{CoN}_4\text{H}_{12}\text{Cl}_3$.

The formula of compound I contains one chloride ion and a complex ion J, which has two stereoisomers.

Draw and label the three-dimensional structures of the two stereoisomers of complex ion J. Include the charge of the complex ion in your diagrams.

[3]

Two students carry out test-tube tests on aqueous solutions of **A** and **B**. They then analyse the results to identify **A** and **B**.

Test		A(aq)	B(aq)
1	NH ₃ (aq) added dropwise	green precipitate C	pale-brown precipitate E
	Excess NH ₃ (aq) added	violet solution D	no further change
2	HNO ₃ (aq)	no change	no change
	followed by Ba(NO ₃) ₂ (aq)	white precipitate F	no change
3	HNO ₃ (aq)	no change	no change
	followed by AgNO ₃ (aq)	no change	yellow precipitate, G

Identify **A** and **B** and write their formulae.

Construct ionic equations for the formation of the products **C–G** from the relevant ions present in **A(aq)** and **B(aq)**.

[7]

(ii) What was the purpose of adding $\text{HNO}_3(\text{aq})$ first in **Test 2** and **Test 3**?

[1]

(iii) **Student 2** accidentally used HCl(aq) instead of $\text{HNO}_3(\text{aq})$ for both **Test 2** and **Test 3**.

What different observations would **Student 2** obtain?

Explain your reasoning.

[3]

(iv) How could the procedure be modified to be more certain of the conclusions from **Test 3**?

[1]

9(a) This question looks at ions and complexes.

* You are provided with two boiling tubes containing solutions of the same ionic compound. The compound contains one cation and one anion from the lists below.

- cations: Fe^{2+} , Mn^{2+} , NH_4^+
- anions: Cl^- , CO_3^{2-} , SO_4^{2-}

Solutions of common laboratory reagents are available.

Plan a series of tests that you could carry out on the samples to identify the ionic compound. Your tests should produce at least one positive result for each ion.

For each test,

- include details of reagents, relevant observations and equations
- explain how your observations allow the ions to be identified.

You may include flowcharts or tables in your answer.

----- [6]

(b) A complex of cobalt has the following composition by mass:

Co, 21.98%; N, 31.35%; H, 6.72%; Cl, 39.75%

(i) Calculate the empirical formula of this complex.

empirical formula = ----- [2]

(ii) The formula of this cobalt complex can be expressed in form $[\text{Co}(\text{L})_m]^{x+}(\text{Cl}^-)_n$

Suggest the chemical formula of $[\text{Co}(\text{L})_m]^{x+}$.

----- [1]

10(a) This question looks at properties of iron compounds and iron ions in different oxidation states.

Fe^{2+} and Fe^{3+} are the most common ions of iron.

(i) Write the electron configuration, in terms of sub-shells, for the Fe^{2+} ion.

-----[1]

(ii) How many orbitals contain an unpaired electron in an ion of Fe^{2+} ?

-----[1]

(b) $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ ions take part in ligand substitution reactions.

An excess of aqueous potassium cyanide, $\text{KCN}(\text{aq})$, is added to an aqueous solution containing $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ ions. A ligand substitution reaction takes place forming a complex ion that has a molar mass of 211.8 g mol^{-1} .

Write an equation for this ligand substitution reaction.

-----[2]

- 11 In basic conditions, α -amino acids form anions with the general formula, $\text{RCH}(\text{NH}_2)\text{COO}^-$. These anions can act as bidentate ligands.

Copper(II) ions can form a square planar complex with anions of the amino acid glycine ($\text{R} = \text{H}$). There are two stereoisomers of this complex, **B** and **C**.

- (i) Draw the **skeletal** formula of the anion of glycine.

[1]

- (ii) Draw diagrams of stereoisomers **B** and **C**.

In your structures, show the ligands as skeletal formulae.

[2]

- (iii) Anion ligands of the amino acid alanine ($\text{R} = \text{CH}_3$) would be expected to form more than two square planar stereoisomers with copper(II) ions.

Explain this statement.

----- [1]

12(a) A redox reaction takes place when copper metal is heated with concentrated sulfuric acid. A blue solution forms and 95.0 cm³ of a colourless gas is collected, measured at RTP. The gas has a mass of 254 mg.

- (i) Write the electron configuration, in terms of sub-shells, for a copper atom.

-----[1]

- (ii) Suggest the identity of the colourless gas and write an equation for the reaction taking place.

State symbols are **not** required in the equation.

Show your working for calculations.

gas: -----

equation: -----

[4]

- (b) A student carries out two experiments based on redox reactions of iron and chromium.

Use the standard electrode potentials below to help you answer the questions that follow.

$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^{-}$	$\rightleftharpoons$	$\text{Fe}(\text{s})$	$E^{\ominus} = -0.44 \text{ V}$
$2\text{H}^{+}(\text{aq}) + 2\text{e}^{-}$	$\rightleftharpoons$	$\text{H}_2(\text{g})$	$E^{\ominus} = 0.00 \text{ V}$
$\text{Fe}^{3+}(\text{aq}) + \text{e}^{-}$	$\rightleftharpoons$	$\text{Fe}^{2+}(\text{aq})$	$E^{\ominus} = +0.77 \text{ V}$
$\text{O}_2(\text{g}) + 4\text{H}^{+}(\text{aq}) + 4\text{e}^{-}$	$\rightleftharpoons$	$2\text{H}_2\text{O}(\text{l})$	$E^{\ominus} = +1.23 \text{ V}$
$\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 14\text{H}^{+}(\text{aq}) + 6\text{e}^{-}$	$\rightleftharpoons$	$2\text{Cr}^{3+}(\text{aq}) + 7\text{H}_2\text{O}(\text{l})$	$E^{\ominus} = +1.33 \text{ V}$
$\text{Cl}_2(\text{g}) + 2\text{e}^{-}$	$\rightleftharpoons$	$2\text{Cl}^{-}(\text{aq})$	$E^{\ominus} = +1.36 \text{ V}$
$\text{H}_2\text{O}_2(\text{aq}) + 2\text{H}^{+}(\text{aq}) + 2\text{e}^{-}$	$\rightleftharpoons$	$2\text{H}_2\text{O}(\text{l})$	$E^{\ominus} = +1.78 \text{ V}$

For each experiment, identify the species causing the observations shown in bold text and write overall equations for any reactions taking place.

State symbols are **not** required in the equations.

(i) Experiment 1

1 The student adds iron filings to dilute hydrochloric acid.

A **green solution** forms and **gas bubbles** are seen.

2 The student bubbles air through the green solution.

The solution turns an **orange-brown colour**.

1:

2:

[3]

(ii) Experiment 2

The student heats a **green solution** of chromium(III) sulfate with dilute acid and hydrogen peroxide, H_2O_2 .

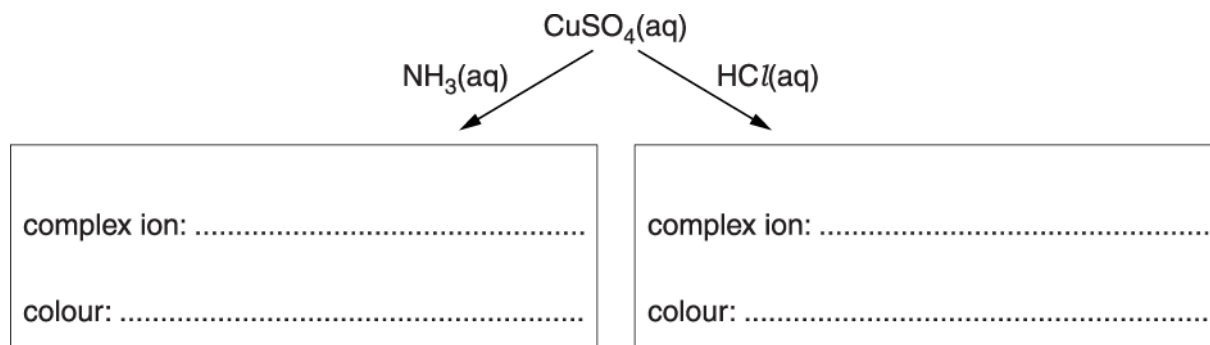
The solution turns an **orange colour**.

[3]

13(a) This question is about the chemistry of copper compounds and complex ions.

The flowchart shows two reactions of aqueous copper(II) sulfate.

In the boxes, write the formulae and colours of the complex ions formed.



- (b) Cu^{2+} ions form a complex ion **A** with two ethanedioate ions and two water molecules. The ethanedioate ion is a bidentate ligand. [3]

The skeletal formula of the ethanedioate ion is shown in Fig. 1.1 below.

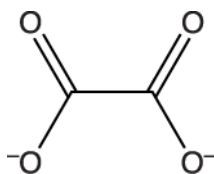


Fig. 1.1

- (i) What is meant by the term *bidentate ligand*?

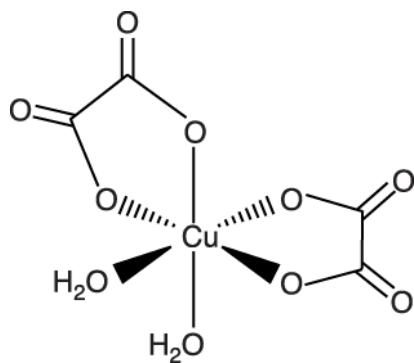
.....

.....

..... [1]

- (ii) The complex ion **A** exists as three stereoisomers.

The shape of one of the stereoisomers is shown below. The charge has been omitted.

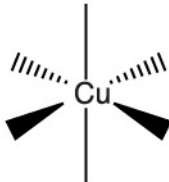
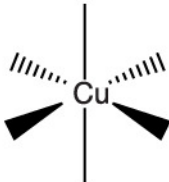


Complex A

Complete the 3D diagrams of the other two stereoisomers of A.

You do **not** need to include any charges.

Indicate with ticks whether the stereoisomers are *cis*, *trans*, optical or a combination of these types.

Stereoisomer														
Type	<table border="1"><tr><td><i>cis</i></td><td></td></tr><tr><td><i>trans</i></td><td></td></tr><tr><td>optical</td><td></td></tr></table>	<i>cis</i>		<i>trans</i>		optical		<table border="1"><tr><td><i>cis</i></td><td></td></tr><tr><td><i>trans</i></td><td></td></tr><tr><td>optical</td><td></td></tr></table>	<i>cis</i>		<i>trans</i>		optical	
<i>cis</i>														
<i>trans</i>														
optical														
<i>cis</i>														
<i>trans</i>														
optical														

[3]

(iii) What is the empirical formula, including the charge, of the complex ion A?

-----[2]

- 14 Hydroxide ions, OH^- , and cyanide ions, CN^- , can react with some aqueous solutions of transition metal compounds.

When nickel(II) sulfate is dissolved in water, a pale green solution forms containing a six-coordinate complex ion **C**.

- Aqueous potassium hydroxide is added to aqueous nickel(II) sulfate.
A green solid **D** forms.
 - An excess of aqueous potassium cyanide is added to aqueous nickel(II) sulfate.
A yellow solution forms containing a four-coordinate complex ion **E** that contains **only** nickel, carbon and nitrogen.
- (i) In **C**, **D** and **E**, nickel has the +2 oxidation state. Suggest the formulae of **C**, **D** and **E**.

Complex ion **C**: _____

Solid **D**: _____

Complex ion **E**: _____

[3]

- (ii) Write equations, and name the types of reaction, for the formation of **D** and **E**.

Formation of solid **D** from aqueous nickel(II) sulfate.

Equation: _____

Type of reaction: _____

Formation of complex ion **E** from complex ion **C**.

Equation: _____

Type of reaction: _____

[4]

15(a) Hydrated copper(II) methanoate, $\text{Cu}(\text{HCOO})_2 \cdot x\text{H}_2\text{O}$, is a copper salt.

A student carries out the procedure below to prepare $\text{Cu}(\text{HCOO})_2 \cdot x\text{H}_2\text{O}$ and to determine the value of x in its formula.

Step 1

The student prepares $\text{Cu}(\text{HCOO})_2 \cdot x\text{H}_2\text{O}$ by reacting a copper compound with aqueous methanoic acid to form $\text{Cu}(\text{HCOO})_2(\text{aq})$ and allowing the solvent to evaporate.

Step 2

The student dissolves 2.226 g of $\text{Cu}(\text{HCOO})_2 \cdot x\text{H}_2\text{O}$ in water and makes up the solution to 250.0 cm^3 .

Step 3

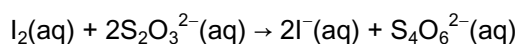
Using a pipette, the student adds 25.0 cm^3 of this solution to a conical flask followed by an excess of $\text{KI}(\text{aq})$.

The $\text{Cu}^{2+}(\text{aq})$ ions react to form a precipitate of copper(I) iodide and $\text{I}_2(\text{aq})$.

In this reaction, 2 mol Cu^{2+} form 1 mol I_2 .

Step 4

The student titrates the iodine in the resulting mixture with $0.0420 \text{ mol dm}^{-3} \text{Na}_2\text{S}_2\text{O}_3(\text{aq})$.



23.5 cm^3 $0.0420 \text{ mol dm}^{-3} \text{Na}_2\text{S}_2\text{O}_3(\text{aq})$ is required to reach the end point.

Complete the electron configuration of copper in

$\text{Cu}(\text{HCOO})_2 \cdot x\text{H}_2\text{O}$: $1s^2$ _____

copper(I) iodide: $1s^2$ _____ [2]

- (b) Choose a suitable copper compound for **step 1**, and write the full equation for the reaction that would take place to form $\text{Cu}(\text{HCOO})_2(\text{aq})$.

State symbols are **not** required.

----- [1]

- (c) Write an ionic equation, including state symbols, for the reaction in **step 3**.

----- [1]

(d) In **step 4**, the student adds a solution to observe the end point accurately.

Name the solution and state the colour change at the end point.

Solution added: _____

Colour change: _____ [2]

(e) Determine the value of x in $\text{Cu}(\text{HCOO})_2 \cdot x\text{H}_2\text{O}$.

Show your working.

[5]

16 What is the reason that zinc is **not** classified as a transition element?

- A Zinc atoms contain a full d-sub-shell.
- B There are no zinc ions with an incomplete d-sub-shell.
- C Zinc does not form complex ions.
- D Zinc ions are colourless.

Your answer

[1]

17 Which statement(s) is/are correct for copper(II) ions?

- 1 They form a copper(II) complex ion with chloride ions that has a square planar shape.
- 2 They can be reduced to copper(I) by iodide ions.
- 3 They have the electron configuration of $1s^2 2s^2 2p^6 3s^2 3p^6 3d^9$.

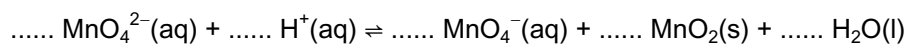
- A 1, 2 and 3
- B Only 1 and 2
- C Only 2 and 3
- D Only 1

Your answer

[1]

18 When heated with dilute acid, $\text{MnO}_4^{2-}(\text{aq})$ ions disproportionate into MnO_4^{-} and MnO_2 .

(i) Balance the equation for this disproportionation reaction.



[1]

(ii) Although $\text{MnO}_4^{2-}(\text{aq})$ ions disproportionate in acidic conditions, $\text{MnO}_4^{2-}(\text{aq})$ ions are stable under alkaline solutions.

Explain this difference in stability, in terms of equilibrium.

[2]

19(a) This question is about reactions and properties of d-block elements.

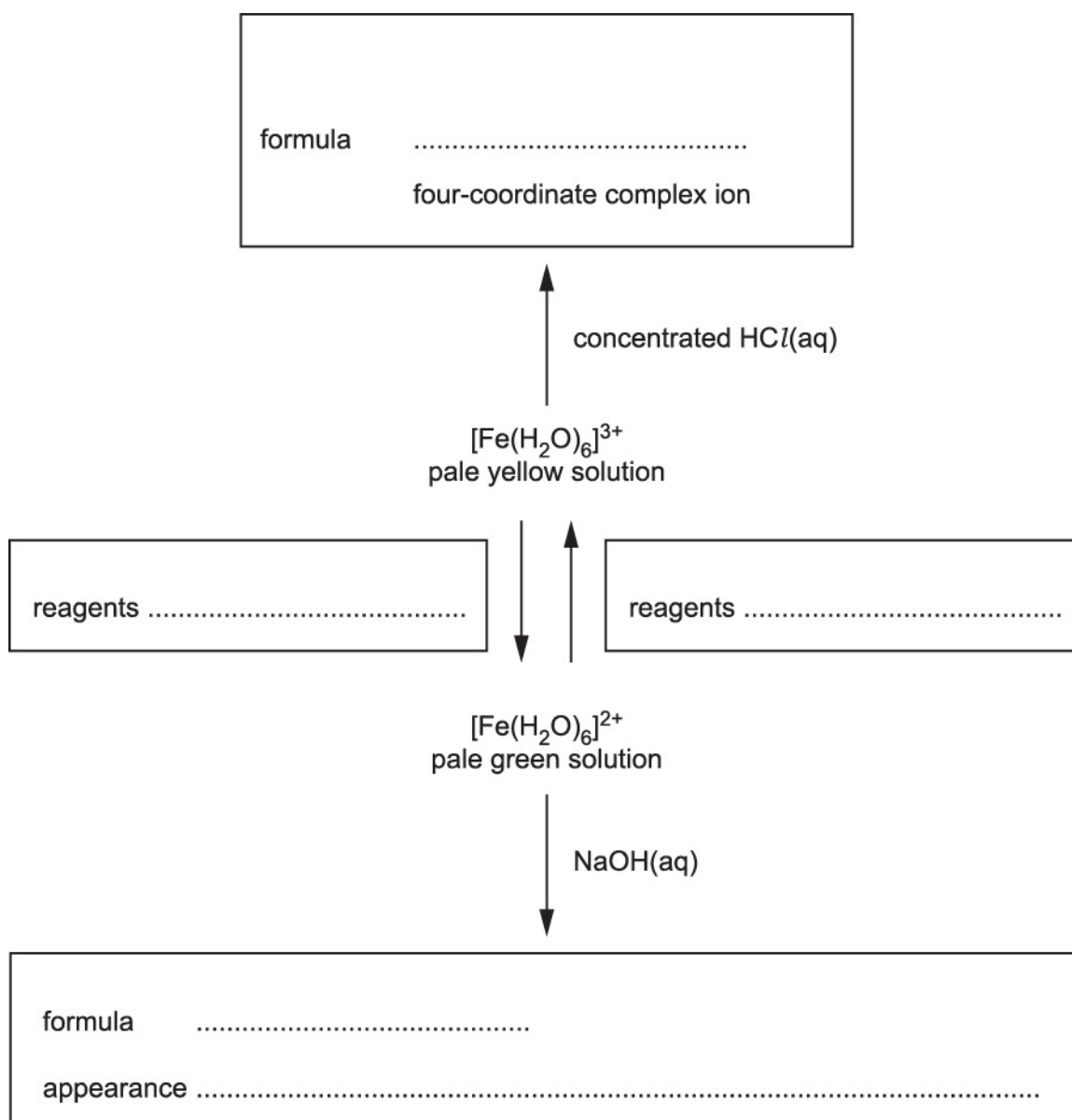
Iron forms many compounds and ions in the +2 and +3 oxidation states.

(i) Complete the electron configuration of iron in its +2 oxidation state.

$1s^2$ [1]

(ii) The flowchart below shows reactions of iron in its +2 and +3 oxidation states.

Complete the flowchart using formulae for reagents and iron-containing products.



(b) A student investigates reactions of cobalt ions, as outlined below.

- A student dissolves cobalt(II) chloride in water. A pink solution forms containing the hexaaqua complex ion **B**.
- The student adds an excess of concentrated ammonia solution to the pink solution until there is no further change.
- A pale brown solution forms which contains the complex ion $[\text{Co}(\text{NH}_3)_6]^{2+}$.

(i) Write the equation for the formation of $[\text{Co}(\text{NH}_3)_6]^{2+}$ from complex ion **B**.

State the type of reaction.

Equation _____

Type of reaction _____ [2]

(ii) Draw a 3-D diagram of the $[\text{Co}(\text{NH}_3)_6]^{2+}$ ion.

On your diagram, show the value of the bond angles involving Co.

[2]

(iii) A solution containing $[\text{Co}(\text{NH}_3)_6]^{2+}$ is reacted as outlined below.

- The solution is warmed with aqueous hydrogen peroxide, $\text{H}_2\text{O}_2(\text{aq})$.
The H_2O_2 oxidises cobalt(II) to cobalt(III), to form a red-brown solution containing a six-coordinate complex ion **C**.
- Concentrated hydrochloric acid is added to the red-brown solution.
Yellow crystals of a complex **D** are formed.

Complex D has the percentage composition by mass:

Co, 22.03%; N, 31.41%, H, 6.73%; Cl, 39.83%.

Determine the formulae of C and D, showing clearly the ligands and any charges.

Show all your working.

[4]

- (iv) Write half equations and an overall equation for the oxidation of $[\text{Co}(\text{NH}_3)_6]^{2+}$ to C by hydrogen peroxide in (iii).

Half equations

Overall equation

[3]

20 Acid rain is caused by the reaction of acid gases with water and oxygen in the air.

Coal often contains traces of iron(II) disulfide, FeS_2 .

FeS_2 is an ionic compound of Fe^{2+} ions and S_2^{2-} ions.

(i) Write the electron configuration, in terms of sub-shells, of an Fe^{2+} ion.

-----[1]

(ii) Draw a 'dot-and-cross' diagram for FeS_2 .

Show outer electrons only.

[2]

21(a) This question is about chemicals used by gardeners.

A garden product contains hydrated ammonium iron(II) sulfate, $(\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2 \cdot x\text{H}_2\text{O}$. $(\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2 \cdot x\text{H}_2\text{O}$ contains 27.55% by mass of water of crystallisation.

Calculate the value of x in the formula $(\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2 \cdot x\text{H}_2\text{O}$.

Show your working.

$x =$ _____ [3]

(b) The garden product in the previous question part is a solid mixture of the following ingredients:

- Hydrated ammonium iron(II) sulfate, $(\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2 \cdot x\text{H}_2\text{O}$, which is soluble in water
- Crushed limestone (calcium carbonate)
- Sand.

(i) Suggest why crushed limestone has been included in this garden product.

----- [1]

(ii) *Plan a procedure on a test tube scale to show that the solid mixture contains the following ions:

- NH_4^+ , Fe^{2+} and SO_4^{2-} present in $(\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2 \cdot x\text{H}_2\text{O}$
- CO_3^{2-} present in crushed limestone.

Show your reasoning, including relevant equations.

----- [6]

- (c) Some gardeners spray crops with 'Bordeaux mixture' which contains several compounds.

One of the compounds in Bordeaux mixture is prepared by a student. The student added aqueous sodium hydroxide to aqueous copper(II) sulfate.

- (i) Write an ionic equation, including state symbols, for the reaction in this preparation.

What would be observed?

Equation _____

Observation _____ [2]

- (ii) It is believed that Cu^{2+} ions in the Bordeaux mixture interact with protein molecules in fungi, preventing growth. Proteins are polyamides.

Suggest the interactions which occur between Cu^{2+} ions and protein molecules in fungi.

_____ [2]

- 22 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]

23 Four pairs of solutions are mixed.

Which pair of solutions forms a white precipitate?

- A $\text{NH}_4\text{Cl}(\text{aq})$ and $\text{NaOH}(\text{aq})$
- B $\text{KBr}(\text{aq})$ and $\text{AgNO}_3(\text{aq})$
- C $\text{FeCl}_3(\text{aq})$ and $\text{NH}_3(\text{aq})$
- D $\text{Cr}_2(\text{SO}_4)_3(\text{aq})$ and $\text{BaCl}_2(\text{aq})$

Your answer

[1]

24 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]

25 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: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$

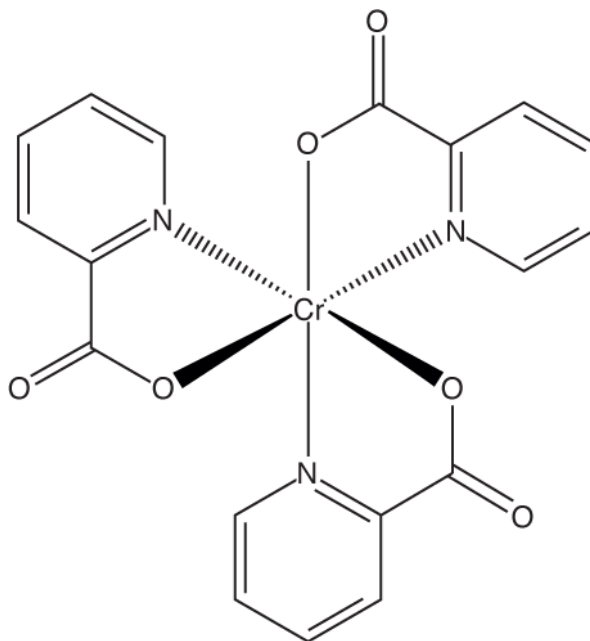
3 Fe^{2+} ion: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^1$

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

Your answer

[1]

- 26 Chromium (III) picolinate, shown below, is a neutral complex that can be prepared from the weak acid, picolinic acid.



Chromium(III) picolinate is used in tablets as a nutritional supplement for chromium.

- (i) Draw the structure of the ligand in chromium(III) picolinate.

[1]

- (ii) A typical tablet of chromium(III) picolinate contains 200 μg of chromium.

Calculate the mass, in g, of chromium (III) picolinate in a typical tablet.

$$1 \mu\text{g} = 10^{-6} \text{ g.}$$

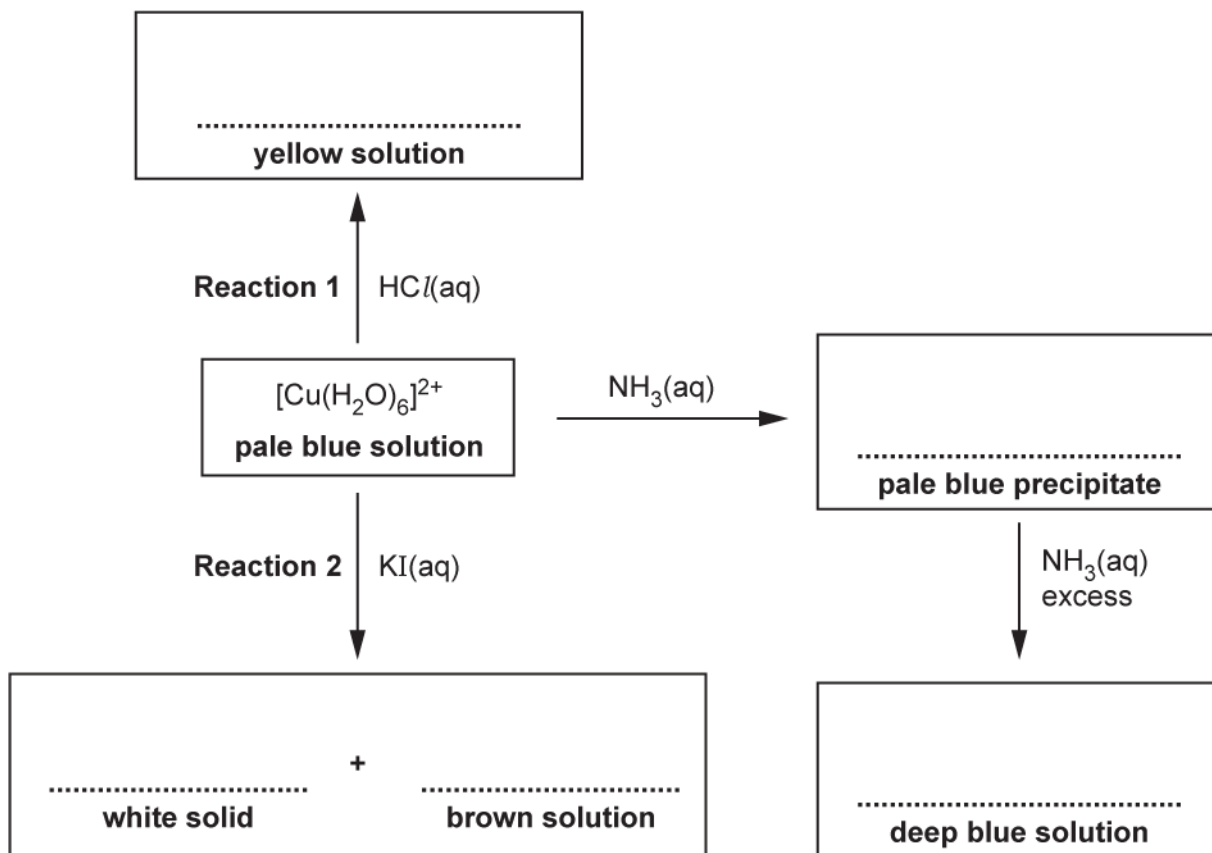
Give your answer to **three** significant figures.

mass = -----g [2]

27(a) This question is about reactions of ions and compounds of transition elements.

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]

(b)



A hydrated nickel(II) complex, **A**, is heated in a crucible to remove the water of crystallisation. The anhydrous complex **B** is formed. The results are shown below.

Mass of crucible + hydrated complex A	= 59.554 g
Mass of crucible + anhydrous complex B	= 58.690 g
Mass of crucible	= 51.257 g

The anhydrous complex **B** is analysed and found to have a molar mass of 309.7 g mol^{-1} and to contain the following percentage composition by mass:

Ni, 18.95%; C, 23.25%; N, 27.12%; H, 7.75%; Cl, 22.93%.

The anhydrous complex **B** contains a cation **C** comprising Ni, C, N and H only.

Cation **C** is six-coordinate, contains three molecules of the bidentate ligand **D**, and exists as optical isomers.

Determine the formula of **A**, **B**, **C** and **D** and show the 3D structures for the optical isomers of **C**.

Show **all** your working.

[6]

28 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]

29(a) 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.

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

Table 21.1

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]

30 Cobalt(II) forms complex ions with water ligands and with chloride ligands.

- With water ligands, cobalt(II) forms a pink octahedral complex ion, $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$.
- With chloride ligands, cobalt(II) forms a blue tetrahedral complex ion.

A student dissolves cobalt(II) sulfate in water in a boiling tube. A pink solution forms.

Experiment 1

The student places the boiling tube in a water bath at 100 °C.

Concentrated hydrochloric acid is added dropwise.

The colour of the solution changes from pink to blue.

Experiment 2

The student places the boiling tube from **experiment 1** in an ice/water bath at 0 °C.

The colour of the solution changes from blue to pink.

- (i) Write the equilibrium equation for the reaction that takes place when the colour of the solution changes.

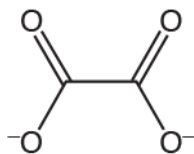
-----[1]

- (ii) Explain the observations and predict whether the formation of the blue colour is exothermic or endothermic.

-----[2]

31 This question is about ethanedioic acid, $(\text{COOH})_2$, and ethanedioate ions, $(\text{COO}^-)_2$.

The ethanedioate ion, shown below, can act as a bidentate ligand.



Fe^{3+} forms a complex ion with three ethanedioate ions.

The complex ion has two optical isomers.

Draw the 3D shapes of the optical isomers.

In your diagrams, show the structure of the ethanedioate ligands and any overall charge.

[3]

32 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]

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

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**.

[1]

34 Which statement about elements in the d block of Period 4 of the periodic table is correct?

- A Cr atoms have the electron configuration: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^1$.
- B Cu^+ ions contain an incomplete 3d sub-shell.
- C Fe^{2+} ions contain 3 unpaired electrons.
- D Sc forms ions with different oxidation states.

Your answer

☐

[1]

35 Which statement(s) for the complex ion $[Co(NH_2CH_2CH_2NH_2)_3]^{2+}$ 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]

36 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]

37 Iron(II) gluconate, $\text{C}_{12}\text{H}_{22}\text{FeO}_{14}$, is the active ingredient in some brands of iron supplements.

A student carries out an experiment to determine the mass of iron(II) gluconate in one tablet of an iron supplement, using the method below.

- Stage 1** The student crushes two tablets and dissolves the powdered tablets in dilute sulfuric acid
- Stage 2** The student makes up the solution from **Stage 1** to 250.0 cm^3 in a volumetric flask.
- Stage 3** The student then titrates 25.0 cm^3 portions of the solution obtained in **Stage 2** with $0.00200\text{ mol dm}^{-3}$ potassium manganate(VII).

The student obtains a mean titre of 13.50 cm^3 .

In this titration, 1 mol of manganate(VII) ions reacts with 5 mol of iron(II) ions.

- (i) Explain why the student used $0.00200\text{ mol dm}^{-3}$ potassium manganate(VII) solution for this titration, rather than the more usual concentration of $0.0200\text{ mol dm}^{-3}$ used in manganate(VII) titrations.

----- [1]

- (ii) Use the student's results to determine the mass, in mg, of iron(II) gluconate in one tablet.

Give your answer to 3 significant figures.

mass of iron(II) gluconate in one tablet = ... mg [5]

- (iii) Some iron supplements contain iron(II) sulfate or iron(II) fumarate.

The information in **Table 18.3** is taken from the labels of two iron supplements, **A** and **B**.

Iron supplement	Iron compound	Mass of iron compound in one tablet / mg
A	iron(II) sulfate, FeSO_4	180
B	iron(II) fumarate, $\text{C}_4\text{H}_2\text{FeO}_4$	210

Table 18.3

Choose which iron supplement, A or B, would provide the greater mass of iron per tablet.

iron supplement: [1]

38 Red blood cells contain haemoglobin.

Explain using ligand substitutions:

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

[3]

39 Transition metal ions can bond to ligands to form complex ions with different shapes.

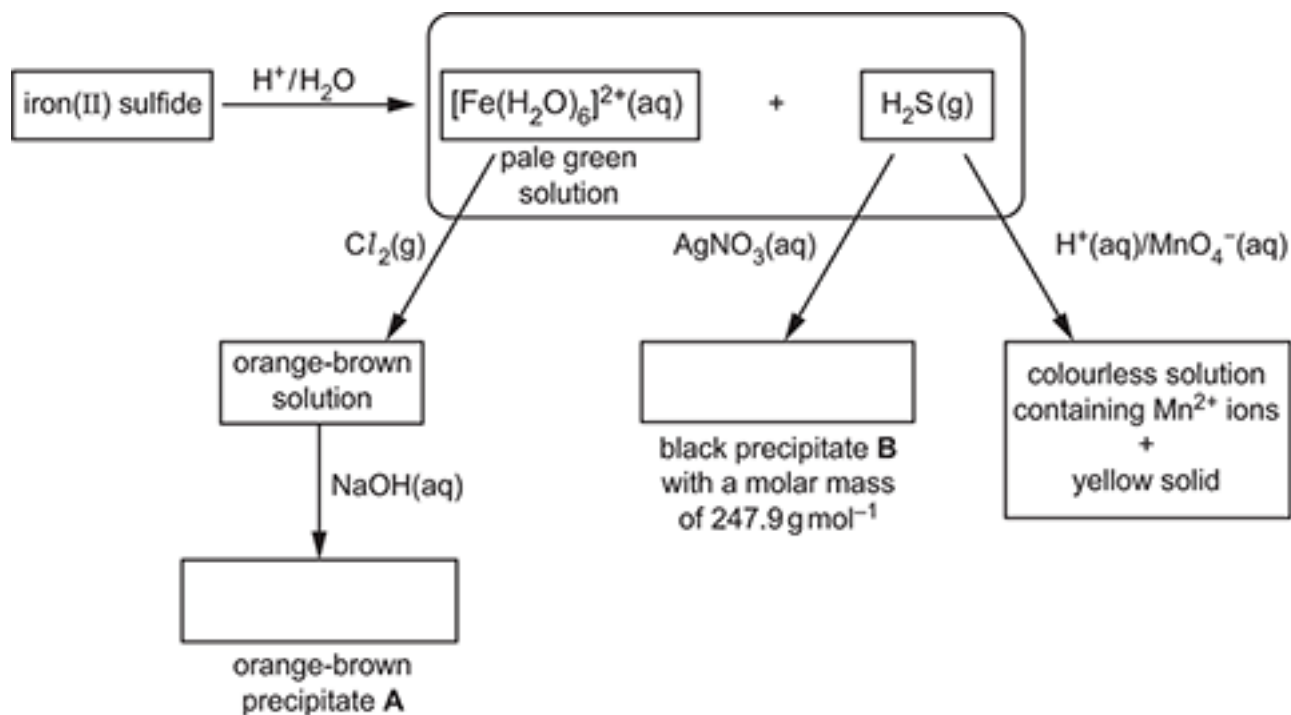
Explain what is meant by the terms **ligand**, **coordination number** and **ligand substitution**, using suitable examples of complex ions with different shapes, limited to monodentate ligands.

Your answer should include diagrams and equations where appropriate.

[6]

40(a) This question is about reactions of iron compounds.

A student carries out the reactions in the flowchart, starting with iron(II) sulfide.



(i) In the boxes, write the formulae of **A** and **B**.

[2]

(ii) The student thinks that the reaction of iron(II) sulfide with $\text{H}^+/\text{H}_2\text{O}$ is a redox reaction.

Explain, with reasons, whether the student is correct.

[1]

(iii) Write the equation for the reaction of $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$ with $\text{Cl}_2(\text{g})$.

[1]

(iv) Construct an equation for the reaction of $\text{H}_2\text{S}(\text{g})$ with $\text{H}^+(\text{aq})/\text{MnO}_4^-(\text{aq})$.

[2]

(b) *Compound **C** is a hydrated ionic compound with the empirical formula: $\text{FeH}_{18}\text{N}_3\text{O}_{18}$.

A student investigates the thermal decomposition of compound **C** as outlined below.

Stage 1

The student gently heats 0.00300 mol of compound **C** to remove the water of crystallisation. 0.486 g of water is collected, leaving 0.00300 mol of the anhydrous compound **D**.

Stage 2

The student strongly heats 0.00300 mol of compound **D**, which decomposes to form a solid oxide **E** (molar mass of 159.6 g mol^{-1}) and 270 cm^3 of a gas mixture, measured at RTP, containing gases **F** and **G**.

Stage 3

The student cools the 270 cm^3 gas mixture of **F** and **G**.

- Gas **F** is a compound that condenses to form 0.414 g of a liquid.
- Gas **G** remains and has a volume of 54 cm^3 , measured at RTP.
Gas **G** is tested and it relights a glowing splint.

Determine the formulae of **C**, **D**, **E**, **F** and **G**.

Show all your working and equations for the reactions.

Blank lined paper for writing.

- 41 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

----- [3]

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

----- [1]

42 * **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**.

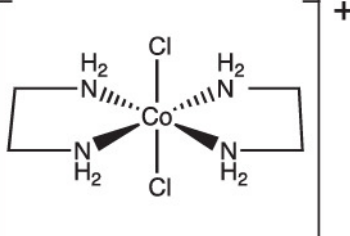
[6]

END OF QUESTION PAPER

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
1	a	i	Donates two electron / lone pairs to a metal ion OR Co^{3+} ✓ DO NOT ALLOW metal (complex contains Co^{3+}) Electron / lone pair on N OR NH_2 (groups) ✓	2	ALLOW 'forms two coordinate bonds / dative covalent / dative bonds' as an alternative for 'donates two electron / lone pairs' <i>Two is required for 1st marking point</i> <i>Two can be implied using words such as 'both' or 'each'</i> For metal ion, ALLOW transition (metal) ion Second mark is for the atom that donates the electron / lone pairs ALLOW both marks for a response that communicates the same using N as the focus: e.g. The two N atoms each donate an electron pair to metal ion Examiner's Comments Most candidates obtained at least one of the available two marks, usually for identifying the role of nitrogen, with its lone pair, as an electron pair donor. The commonest omission was the required coordinate bond formation to the transition metal ion.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	$[\text{Co}(\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2)_2\text{Cl}_2]^+$ ✓	1	Square brackets AND + charge required DO NOT ALLOW any charges included within square brackets ALLOW $[\text{Co}(\text{C}_2\text{H}_8\text{N}_2)_2\text{Cl}_2]^+$ OR $[\text{CoC}_4\text{H}_{16}\text{N}_4\text{Cl}_2]^+$ ALLOW structural OR displayed OR skeletal formula OR mixture of the above (as long as unambiguous) IGNORE $[\text{Co}(\text{en})_2\text{Cl}_2]^+$ <i>simplifies question</i> Within formula, ALLOW ... $(\text{Cl})_2$, (Cl_2) ALLOW CO Within the context of the question, CO is Co Examiner's Comments Success depended on a systematic approach with both the number of ligands and the overall charge. The examiners did not allow formulae containing charges within the required square brackets as collectively the overall charge displayed would then be wrong. The commonest error seen was an incorrect overall charge, either as – or as 3+.
		iii	6 ✓	1	Examiner's Comments Most candidates responded correctly with a coordination number of 6 although there was the usual incorrect response seen of '4' from counting each ethanediamine ligand just once.
		iv		3	FULL ANNOTATIONS MUST BE USED ----- IGNORE charges (anywhere) and labels (even if wrong) Square brackets NOT required Must contain 2 'out wedges', 2 'in wedges' and 2 lines in plane of paper OR 4 lines, 1 'out wedge' and 1 'in wedge':

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
	Note: For each structure, ALL NH₂ groups must be shown AND bonding between Co AND N of NH₂. For H₂NCH₂CH₂NH₂, ALLOW C—C without Hs and ----- IF NH₂ shown without Hs, e.g. penalise first time ONLY ----- IF ALL 3 isomers are 'correct', but 2 x Cl AND no Ns, e.g. AWARD 1 mark		For bond into paper, ALLOW: ALLOW following geometry throughout: TAKE CARE: structures may be in different orientations. For H₂NCH₂CH₂NH₂, ALLOW ALLOW NH₂ H₂N <i>(connectivity within 'loop' only)</i> If Cl₂s are shown instead of Cl, penalise 1st time only Examiner's Comments This type of question has been encountered on previous papers and candidates were generally comfortable with drawing stereoisomers. The examiners did require the connecting amine groups to be shown including bonding from the N atoms to the metal ion to full credit. Intermediate marks were available if H atoms or NH₂ groups had been omitted. In general, candidates displayed 3D diagrams very competently using 'in' and 'out' wedges. Some candidates did manage to repeat the <i>trans</i> isomer once or even twice. Most candidates displayed the <i>cis</i> optical isomers as clear mirror images and this strategy is recommended. A few candidates instead chose to rotate the whole structure and whether the second diagram was a different optical isomer or the same structure rotated was then largely down to luck.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b	i	O_2 / oxygen bonds to $Fe^{2+}/Fe(II)$ ✓ Fe^{2+} / $Fe(II)$ essential for 1st marking point (When required,) O_2 substituted OR O_2 released ✓ Fe^{2+} not required for 2nd marking point (e.g. IGNORE Fe)	2	ASSUME that 'it' refers to oxygen ALLOW O_2 binds to Fe^{2+} OR O_2 donates electron pair to Fe^{2+} OR O_2 is a ligand with Fe^{2+} IGNORE O_2 reacts with Fe^{2+} OR O_2 is around Fe^{2+} ALLOW bond to O_2 breaks when O_2 required OR H_2O replaces O_2 OR vice versa ALLOW CO_2 replaces O_2 OR vice versa ALLOW O_2 bonds / binds reversibly Examiner's Comments The majority of candidates secured one of the available two marks for describing ligand substitution between O_2 and either H_2O or CO_2. The second mark required a specific reference to the role of Fe^{2+}; this was often omitted with responses instead predominately discussing the role of haem or iron.
		ii	$(K_{stab} =) \frac{[HbO_2(aq)]}{[Hb(aq)][O_2(aq)]}$ ✓ ALL Square brackets essential	1	ALLOW expression without state symbols (given in question) Examiner's Comments As with 3(a) the K_{stab} expression was shown correctly by almost all candidates, the only mistakes being the very occasional inverted expression or use of '+' within the denominator.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	Both marks require a comparison Stability constant / K_{stab} value with CO is greater (than with complex in O₂) ✓ (Coordinate) bond with CO is stronger (than O₂) OR CO binds more strongly ✓	2	IGNORE (complex with) CO is more stable ALLOW bond with CO is less likely to break (than O₂) OR CO is a stronger ligand (than O₂) OR CO has greater affinity for ion / metal / haemoglobin (than O₂) ALLOW CO bond formation is irreversible OR CO is not able to break away IGNORE CO bonds more easily OR CO complex forms more easily Examiner's Comments The majority of candidates obtained both marks by following the cues in the question for an explanation in terms of CO having a greater bond strength and higher stability constant than O₂ with haemoglobin.
			Total	12	

Mark Scheme

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2	a		$\text{Fe}_2\text{O}_3 + 3\text{Cl}_2 + 10\text{OH}^- \rightarrow 2\text{FeO}_4^{2-} + 6\text{Cl}^- + 5\text{H}_2\text{O} \checkmark\checkmark$ First mark for all 6 species Second mark for balancing	2	ALLOW multiples ALLOW oxidation half equation for two marks $\text{Fe}_2\text{O}_3 + 10\text{OH}^- \rightarrow 2\text{FeO}_4^{2-} + 5\text{H}_2\text{O} + 6\text{e}^-$ Correct species would obtain 1 mark – <i>question: equation for oxidation</i> ALLOW variants forming H^+ for 1 mark, e.g: $\text{Fe}_2\text{O}_3 + 3\text{Cl}_2 + 5\text{OH}^- \rightarrow 2\text{FeO}_4^{2-} + 6\text{Cl}^- + 5\text{H}^+$ $\text{Fe}_2\text{O}_3 + 3\text{Cl}_2 + 5\text{OH}^- \rightarrow 2\text{FeO}_4^{2-} + 5\text{HCl} + \text{Cl}^-$ Examiner's Comments The information needed to write the equation was largely within the information provided for step 1. In step 1, candidates were provided with three reactants and two of the products. They were also told that the reaction was carried out using an excess of hydroxide ions, so any potential H^+ ions produced would be neutralised to water. Only the very best candidates were able to interpret this information to score both marks for the correct equation. Many attempts seen did not start with iron(III) oxide. When arriving at a complete equation, candidates are recommended to check the overall charge on either side. This must balance, a feature not seen in the majority of responses. One mark was available for an equation with all species correct, including water as the third product, or a 'correct' equation but with H^+ produced.

Mark Scheme

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	b		$\text{Ba}^{2+}(\text{aq}) + \text{FeO}_4^{2-}(\text{aq}) \rightarrow \text{BaFeO}_4(\text{s}) \checkmark$	1	Balanced ionic equation AND state symbols required DO NOT ALLOW +2 or –2 for ionic charges Examiner's Comments As with 8(a), the relevant information was mostly included within the referenced part: step 2. The responses were very disappointing as the required equation is very similar to a simple precipitation reaction between silver and halide ions. The requirement for state symbols was clearly stated but often omitted from otherwise correct equations.
	c		Reason can ONLY be correct from correct reducing agent ----- <i>reducing agent:</i> I^- OR KI $\checkmark$ I^- adds / donates / loses electrons AND to FeO_4^{2-} OR to BaFeO_4 OR to Fe(VI) or to Fe(+6) $\checkmark$ ALLOW Fe(6+) OR Fe^{6+}	2	IGNORE H^+ OR acidified ALLOW iodide / potassium iodide but DO NOT ALLOW iodine ALLOW I^- loses electrons AND to form I_2 ALLOW Fe(6+) OR Fe^{6+} Examiner's Comments The majority of candidates identified iodide ions or potassium iodide as the oxidising agent. Iodine was often recognised as the product but the explanation was usually in terms of oxidation number despite the question asking for electrons – very much a case of reading the question. Precise language was also required as iodine and iodide are rather different, especially as iodine is the product. The best responses discussed the species being reduced, BaFeO_4 or Fe(VI).

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
	d	FIRST, CHECK THE ANSWER ON ANSWER LINE IF answer = 51.8%, award 4 marks. ----- $n(\text{S}_2\text{O}_3^{2-}) \text{ used} = 0.1000 \times \frac{26.4}{1000} = 2.64 \times 10^{-3} \text{ (mol) } \checkmark$ $n(\text{FeO}_4^{2-}) = \frac{1}{2} \times \frac{2}{3} \times 2.64 \times 10^{-3} = 8.8(0) \times 10^{-4} \text{ (mol) } \checkmark$ Mass BaFeO₄ in sample $= 8.8 \times 10^{-4} \times 257.1 \text{ g} = 0.226248 \text{ g } \checkmark$ $\% \text{ purity} = \frac{0.226248}{0.437} \times 100 = 51.8\% \checkmark$ MUST be to one decimal place (in the question) ----- As an alternative for the final two marks, ALLOW: $\text{Theoretical amount of BaFeO}_4 = \frac{0.437}{257.1} = 0.00170 \text{ (mol) } \checkmark$ $\% \text{ purity} = \frac{8.8 \times 10^{-4}}{1.70 \times 10^{-3}} \times 100 = 51.8\% \checkmark$	4	FULL ANNOTATIONS MUST BE USED ----- For alternative answers, look first at common ECFs below. Then check for ECF credit possible using working below IF a step is omitted but subsequent step subsumes previous, then award mark for any missed step ----- Working must be to at least 3 SF throughout until final % mark BUT ignore trailing zeroes, ie for 0.880 allow 0.88 ECF answer above $\times \frac{1}{2} \times \frac{2}{3}$ This mark may be seen in 2 steps via I₂ but the mark is for both steps combined ECF $257.1 \times$ answer above $\text{ECF } \frac{\text{answer above}}{0.437} \times 100$ ALLOW 51.7% FROM 0.226 g BaFeO₄ (earlier rounding) ----- Common ECFs: No $\times \frac{2}{3}$ for $n(\text{FeO}_4^{2-})$: % purity = 77.7%/77.6% 3 marks No $\div 2$ for $n(\text{FeO}_4^{2-})$: % purity = 25.9% 3 marks 24.6 used instead of 26.4: % purity = 48.2% 3 marks Examiner's Comments After the information-finding demands of parts (a)–(c), candidates were on much firmer territory here with a stock redox titration problem. Many candidates secured all 4 marks and most were able to obtain some marks along the way. The hardest mark was the step from the initial amount of Na₂S₂O₃ to the amount of BaFeO₄. Answer: 51.8%

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	e		gas: O₂ ✓ precipitate: Fe(OH)₃ ✓ equation: 2FeO₄²⁻ + 5H₂O → 1½O₂ + 2Fe(OH)₃ + 4OH⁻ ✓ OR 2FeO₄²⁻ + H₂O + 4H⁺ → 1½O₂ + 2Fe(OH)₃	3	DO NOT ALLOW names IGNORE a balancing number shown before a formula ALLOW Fe(OH)₃(H₂O)₃ ALLOW multiples ALLOW 2FeO₄²⁻ + 11H₂O → 1½O₂ + 2Fe(OH)₃(H₂O)₃ + 4OH⁻ Examiner's Comments This part required candidates to construct an equation for an unfamiliar reaction. Candidates were reasonably competent in identifying the gas as O₂ and precipitate as Fe(OH)₃. Unfortunately, some responded with 'oxygen' despite the formulae being asked for in the question. The correct equation proved to be the hardest mark on the paper, being seen extremely rarely. As with the equation in 8(a), often the overall charge didn't balance on either side of the equation, a consideration that would have led to many more correct responses.
			Total	12	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
3	a		For equations, IGNORE any state symbols; ALLOW multiples ----- Any correct equation for a reaction catalysed by a transition element, compound or ion AND transition element, compound or ion (by formula or name) ✓	1	EXAMPLES $\text{N}_2 + 3\text{H}_2 \rightleftharpoons 2\text{NH}_3$ (allow $\rightarrow$) AND Fe / iron oxide $2\text{SO}_2 + \text{O}_2 \rightleftharpoons 2\text{SO}_3$ (allow $\rightarrow$) AND V_2O_5 / Pt $2\text{CO} + 2\text{NO} \rightarrow 2\text{CO}_2 + \text{N}_2$ AND Pt / Pd / Rh / Au Equation for any alkene + $\text{H}_2 \rightarrow$ alkane AND Ni / Pt / Pd $\text{C}_6\text{H}_6 + \text{Cl}_2 \rightarrow \text{C}_6\text{H}_5\text{Cl} + \text{HCl}$ AND Fe / FeCl_3 / Fe^{3+} $\text{C}_6\text{H}_6 + \text{Br}_2 \rightarrow \text{C}_6\text{H}_5\text{Br} + \text{HBr}$ AND Fe / FeBr_3 / Fe^{3+} $2\text{H}_2\text{O}_2 \rightarrow 2\text{H}_2\text{O} + \text{O}_2$ AND MnO_2 For other examples, CHECK with TL Examiner's Comments This part allowed candidates to select any transition element to illustrate catalysis. The commonest seen were iron, in the Haber process, nickel, in the hydrogenation of alkenes, and FeBr_3, in the bromination of benzene. Equations were usually correct. The examiners did allow any reaction that was catalysed by a transition element. It was disappointing to see some equations that showed ammonia as NH_2 or NH_4^+.
	b	i	Donates two electron pairs (to a metal ion) AND forms two coordinate bonds (to a metal ion) ✓ <i>NOTE: Metal ion not required as Ni^{3+} is in the question</i>	1	ALLOW lone pairs for electron pairs ALLOW dative (covalent) bonds for coordinate bonds TWO is only needed once, e.g. Donates two electron pairs to form coordinate bonds Donates electron pairs to form two coordinate bonds Examiner's Comments Most candidates obtained this mark in terms of donation by two electron pairs to form two coordinate or dative covalent bonds. Some candidates omitted donation or formed one coordinate bond only.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	$C_3H_{10}N_2$ ✓	1	ALLOW in any order IGNORE structure Examiner's Comments Most candidates were able to identify the three bidentate ligands in $C_9H_{30}N_6Ni^{3+}$ and the correct response of $C_3H_{10}N_2$ was commonly seen. The question asked for a molecular formula and structural or other formulae were not credited. Weaker candidates often responded with $C_9H_{30}N_6$.
		iii	MARK INDEPENDENTLY ----- $H_2NCH_2CH_2CH_2NH_2$ ✓ Each N OR each NH_2 OR amine group has a lone pair / electron pair OR lone pairs shown on N atoms in structure ✓	2	ALLOW correct structural OR displayed OR skeletal formula OR mixture of the above (as long as unambiguous) ALLOW $H_2NCH_2CH(CH_3)NH_2$ OR $H_2NCH(CH_2CH_3)NH_2$ ALLOW secondary or tertiary diamines or mixture IGNORE complex ion FOR other examples, CHECK with TL Examiner's Comments Most candidates were able to produce a diamine of $C_3H_{10}N_2$. A displayed or semi-displayed formula was the commonest response seen with propane-1,3-diamine being the commonest isomer seen (any possible diamine of $C_3H_{10}N_2$ was credited). The role of the two nitrogen atoms in providing the electron pairs was usually described, although examiners also credited this feature if seen in the structure.
		iv	6 ✓	1	Examiner's Comments Most candidates responded correctly with a coordination number of 6 although there was the usual incorrect response seen of '3' from counting each bidentate ligand instead of the number of the coordinate bonds.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		v	3-D diagrams of BOTH optical isomers required for the mark 	1	In this part, Charge AND Square brackets NOT required IGNORE N or attempts to draw structure of bidentate ligand Other orientations possible but all follow same principle with 2nd structure being a mirror image of the first Examiner's Comments In past sessions, candidates have been required to draw out stereoisomers and this question proved to be much more straightforward. Only the very weakest candidates were unable to complete the diagrams to provide two mirror image forms.
	c		<i>Quality of written communication</i> Observation must be linked to the correct reaction REACTIONS OF AQUEOUS Cu^{2+} ----- REACTION OF Cu^{2+} with NaOH(aq) Correct balanced equation $\text{Cu}^{2+}(\text{aq}) + 2\text{OH}^{-}(\text{aq}) \rightarrow \text{Cu}(\text{OH})_2(\text{s})$ ✓ state symbols not required Observation blue precipitate / solid ✓	2	FULL ANNOTATIONS MUST BE USED THROUGHOUT ALLOW some reactions for Cu^{2+} and some for Co^{2+} ALLOW equilibrium signs in all equations IGNORE any incorrect initial colours IGNORE state symbols IGNORE an incorrect formula for an observation ----- ALLOW $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 2\text{OH}^{-} \rightarrow \text{Cu}(\text{OH})_2(\text{H}_2\text{O})_4 + 2\text{H}_2\text{O}$ ALLOW full or 'hybrid' equations, e.g. $\text{Cu}^{2+} + 2\text{NaOH} \rightarrow \text{Cu}(\text{OH})_2 + 2\text{Na}^{+}$ $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 2\text{OH}^{-} \rightarrow \text{Cu}(\text{OH})_2 + 6\text{H}_2\text{O}$ $\text{CuSO}_4 + 2\text{NaOH} \rightarrow \text{Cu}(\text{OH})_2 + \text{Na}_2\text{SO}_4$ ALLOW any shade of blue

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			REACTION OF Co^{2+} WITH excess $\text{NH}_3(\text{aq})$ Correct balanced equation $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 4\text{NH}_3 \rightarrow [\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+} + 4\text{H}_2\text{O}$ ✓ Observation deep / dark blue (solution) ✓	2	IGNORE initial precipitation of $\text{Cu}(\text{OH})_2$ IGNORE $[\text{Cu}(\text{NH}_3)_4]^{2+}$ ALLOW royal blue, ultramarine blue or any blue colour that is clearly darker than for $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ DO NOT ALLOW deep blue precipitate for observation
			REACTION OF Cu^{2+} WITH $\text{HCl}(\text{aq})$ Correct balanced equation $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 4\text{Cl}^- \rightarrow [\text{CuCl}_4]^{2-} + 6\text{H}_2\text{O}$ ✓ Observation yellow (solution) ✓ <i>Quality of written communication</i> Observation must be linked to the correct reaction REACTIONS OF AQUEOUS Co^{2+} ----- REACTION OF Co^{2+} with $\text{NaOH}(\text{aq})$ Correct balanced equation $\text{Co}^{2+}(\text{aq}) + 2\text{OH}^-(\text{aq}) \rightarrow \text{Co}(\text{OH})_2(\text{s})$ ✓ state symbols not required Observation blue precipitate / solid ✓	2	IGNORE mention of different concentrations of HCl ALLOW CuCl_4^{2-} i.e. no brackets OR $\text{Cu}(\text{Cl})_4^{2-}$ ALLOW $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 4\text{HCl} \rightarrow [\text{CuCl}_4]^{2-} + 6\text{H}_2\text{O} + 4\text{H}^+$ IGNORE $\text{Cu}^{2+} + 4\text{Cl}^- \rightarrow \text{CuCl}_4^{2-}$ ALLOW green–yellow OR yellow–green DO NOT ALLOW yellow precipitate for observation FULL ANNOTATIONS MUST BE USED THROUGHOUT ALLOW some reactions for Cu^{2+} and some for Co^{2+} ALLOW equilibrium signs in all equations IGNORE any incorrect initial colours IGNORE state symbols IGNORE an incorrect formula for an observation ----- ALLOW $[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 2\text{OH}^- \rightarrow \text{Co}(\text{OH})_2(\text{H}_2\text{O})_4 + 2\text{H}_2\text{O}$ ALLOW full or ‘hybrid’ equations, e.g. $\text{Co}^{2+} + 2\text{NaOH} \rightarrow \text{Co}(\text{OH})_2 + 2\text{Na}^+$ $[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 2\text{OH}^- \rightarrow \text{Co}(\text{OH})_2 + 6\text{H}_2\text{O}$ $\text{CoSO}_4 + 2\text{NaOH} \rightarrow \text{Co}(\text{OH})_2 + \text{Na}_2\text{SO}_4$ ALLOW any shade of blue IGNORE changes in colour over time

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
	REACTION OF Co^{2+} WITH excess $\text{NH}_3(\text{aq})$ Correct balanced equation $[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 6\text{NH}_3 \rightarrow [\text{Co}(\text{NH}_3)_6]^{2+} + 6\text{H}_2\text{O}$ ✓ Observation brown / yellow (solution) ✓ REACTION OF Co^{2+} WITH $\text{HCl}(\text{aq})$ Correct balanced equation $[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 4\text{Cl}^- \rightarrow [\text{CoCl}_4]^{2-} + 6\text{H}_2\text{O}$ ✓ Observation blue (solution) ✓		IGNORE initial precipitation of $\text{Co}(\text{OH})_2$ ALLOW any shade of brown or yellow DO NOT ALLOW brown / yellow precipitate for observation IGNORE mention of different concentrations of HCl ALLOW CoCl_4^{2-} i.e. no brackets OR $\text{Co}(\text{Cl})_4^{2-}$ ALLOW $[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 4\text{HCl} \rightarrow [\text{CoCl}_4]^{2-} + 6\text{H}_2\text{O} + 4\text{H}^+$ IGNORE $\text{Co}^{2+} + 4\text{Cl}^- \rightarrow \text{CoCl}_4^{2-}$ ALLOW any shades of blue DO NOT ALLOW blue precipitate for observation Examiner's Comments This question assessed knowledge and understanding of precipitation and ligand substitution reactions of transition metal ions. The question discriminated extremely well between well-prepared and poorly-prepared candidates. The well-prepared often collected the full six marks with comparative ease. However, marks were sometimes squandered by incorrect balancing of equations (e.g. formation of $2\text{H}_2\text{O}$ rather than $4\text{H}_2\text{O}$ with NH_3), careless positioning of numbers (such as $\text{Cu}(\text{OH}_2)$ and $[\text{Cu}(\text{H}_2\text{O}_6)]^{2+}$) or omission of charges (such as $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]$). The observations were very well known with yellow, rather than green, usually seen for CuCl_4^{2-}. It was sad to see the responses of poorly-prepared candidates that had clearly been invented in the exam. Often these scored no marks or perhaps one for remembering that copper(II) hydroxide is a blue precipitate. Cobalt tended to be the choice of weaker candidates. Some candidates mixed and matched between copper and cobalt and this

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					approach was fully credited. For precipitation, the specification allows a simple equation in terms of $\text{Cu}^{2+}(\text{aq})$ rather than complex ions. It was relatively common to see an equation for the precipitation reaction of $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ with hydroxide ions forming $[\text{Cu}(\text{OH})_2(\text{H}_2\text{O})_4]$ and this approach gained full credit if the equations were correctly balanced. The two equations for ligand substitution required complex ions throughout. It should be noted that the specification requires the complex ion $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ and the simpler representation of $[\text{Cu}(\text{NH}_3)_4]^{2+}$ was not credited. $[\text{Cu}(\text{NH}_3)_6]^{2+}$ was a common incorrect complex ion seen.
			Total	13	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
4	a	i	Fe^{2+} : $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6$ ✓	2	ALLOW 4s before 3d, ie $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6$ ALLOW $1s^2$ written after answer prompt (ie $1s^2$ twice)
		i	Br^- : $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6$ ✓		ALLOW upper case D, etc and subscripts, e.g. 4S₂3D₁ ALLOW for Fe^{2+} 4s⁰ DO NOT ALLOW [Ar] as shorthand for $1s^2 2s^2 2p^6 3s^2 3p^6$ Look carefully at $1s^2 2s^2 2p^6 3s^2 3p^6$ – there may be a mistake Examiner's Comments Few candidates produced two incorrect electron configurations but there were many mistakes seen for either species. For Fe^{2+}, the commonest error was for loss of electrons from the 3d rather than 4s sub-shell of an Fe atom. For a Br^- ion, it was common to see the electron configuration of a Br atom. Surprisingly a common error was to see $4p^4$ rather than $4p^6$ from loss rather than gain of an electron. Only just over half the candidates showed two correct configurations so clearly more care is needed when answering.

Mark Scheme

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		ii	With Cl_2 AND Br_2 AND I_2 products are Fe^{2+} (AND halide ion) FeCl_2 AND FeBr_2 AND FeI_2 ✓ OR Evidence that two electrode potentials have been compared for at least ONE reaction, ✓ e.g. $\text{Fe} -0.44$ AND $\text{Cl}_2 +1.36$ e.g. Iron has more / most negative electrode potential With Cl_2 AND Br_2, products are Fe^{3+} (AND halide ion) FeCl_3 AND FeBr_3 ?	3	FULL ANNOTATIONS NEEDED ALLOW products within equations (even if equations are not balanced) IF stated, IGNORE reactants ALLOW response in terms of positive 'cell reactions', e.g $\text{Fe} + \text{Cl}_2 \rightarrow \text{Fe}^{2+} + 2\text{Cl}^-$ $E = (+)1.80 \text{ V}$ IGNORE comments about reducing and oxidising agents and electrons Examiner's Comments The majority of candidates predicted that Fe would react with all three halogens to form Fe^{2+} ions, supported by equations and electrode potential data. Many simply stated that Fe has the more negative E value (or the halogens the more positive value). It was also common to see cell voltages used, such as $+0.98 \text{ V}$ for a reaction between iron and iodine. Both approaches were credited. The most able candidates correctly predicted that Fe^{2+} ions, initially formed from the reaction of iron with bromine and chlorine, would then be oxidised to Fe^{3+}. The best answers showed exceptional understanding. Candidates are advised to consider all the information supplied in a question as the majority had ignored completely the $\text{Fe}^{3+}/\text{Fe}^{2+}$ data.

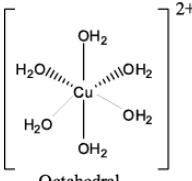
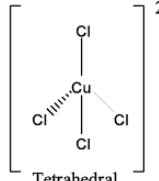
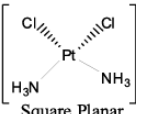
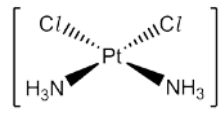
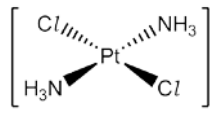
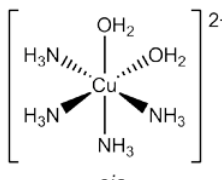
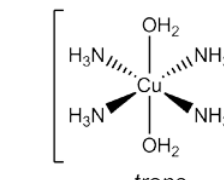
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b		BOTH EQUATIONS REQUIRE IONS PROVIDED IN QUESTION Reaction 1: 2 marks 1st mark for ALL CORRECT species e.g.: $\text{Fe}^{2+} + \text{NO}_3^- + \text{H}^+ \rightarrow \text{Fe}^{3+} + \text{NO} + \text{H}_2\text{O}$ 2nd mark for CORRECT balanced equation $3\text{Fe}^{2+} + \text{NO}_3^- + 4\text{H}^+ \rightarrow 3\text{Fe}^{3+} + \text{NO} + 2\text{H}_2\text{O}$ ✓✓ ----- Reaction 2: 1 mark $[\text{Fe}(\text{H}_2\text{O})_6]^{2+} + \text{NO} \rightarrow [\text{Fe}(\text{H}_2\text{O})_5\text{NO}]^{2+} + \text{H}_2\text{O}$ ✓	3	ALLOW correct multiples throughout ALLOW equilibrium signs in all equations For 1st mark, IGNORE e^- present Check carefully for correct charges Examiner's Comments This part required candidates to interpret unfamiliar information to construct reactions for redox and ligand substitution reactions. Marks were sometimes wasted by incorrect balancing of equations or careless positioning of numbers. This part discriminated extremely well. For the redox equation, common mistakes were omission of species (such as H^+) failure to balance the redox reaction by charge (with the '3' balancing numbers for Fe^{2+} and Fe^{3+} being omitted) or inclusion of e^- on one side of the equation. For the ligand substitution equation, H_2O was sometimes omitted on the right-hand side and careless positioning of numbers, such as (H_2O_5) was sometimes seen. Candidates are recommended to check all species very carefully for any such slips.
			Total	8	
5			D	1	
			Total	1	
6			B	1	
			Total	1	

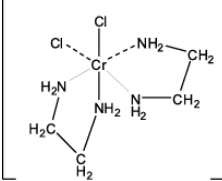
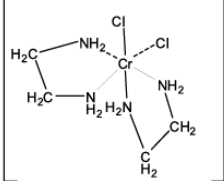
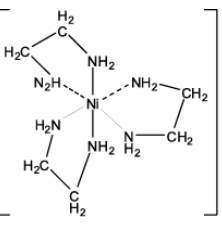
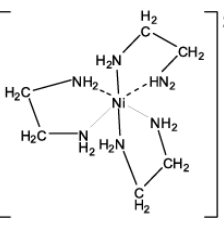
Mark Scheme

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7	a		1 $n(\text{AgCl}) \text{ formed} = \frac{7.695}{143.5} = 0.05362 \text{ (mol)}$ 2 0.0180 mol of B forms 0.05362 mol of Cl^- No of Cl^- ions in formula of B = $\frac{0.05362}{0.0180} = 3$ 3 Molar mass of B = $\frac{2.856}{0.0180} = 158.7 \text{ (g mol}^{-1}\text{)}$ $158.7 - (3 \times 35.5) = 52.2$ which is chromium 4 $n(\text{H}_2\text{O}) = \frac{1.944}{18} = 0.108 \text{ (mol)}$ 0.0180 mol CrCl_3: 0.108 mol H_2O OR 1 mol CrCl_3: 6 mol H_2O A $\text{CrCl}_3 \cdot 6\text{H}_2\text{O}$ (from points 2, 3 and 4) B CrCl_3 (from points 2 and 3) D $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$ (from determination of A and understanding of reaction with water) E $\text{Cr}(\text{OH})_3$ (from understanding of reaction of D with aqueous hydroxide)	9	ALLOW Alternative working throughout

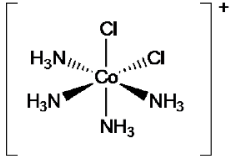
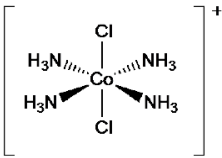
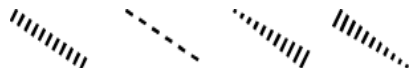
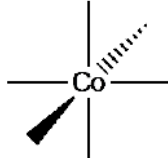
Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
b	<i>* Please refer to the marking instruction point 10 for guidance on how to mark this question.</i> Level 3 (5–6 marks) Links together names of shapes with correct 3-D diagrams AND Appreciates the two different types of isomerism and labels diagrams appropriately. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> <i>Demonstrates clear and confident knowledge of relevant technical language using the terms</i> <i>non-superimposable mirror images within optical isomerism</i> <i>opposite and adjacent / same side in cis–trans.</i> Level 2 (3–4 marks) Names and labels at least two of the shapes appropriately giving 3-D diagrams AND Appreciates that two types of isomerism exist in transition metal chemistry, gives diagrams to illustrate at least one pair of isomers and names them correctly. <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> <i>Answers question with a sound grasp of relevant technical language using the terms.</i> <i>tetrahedral, octahedral</i> <i>cis–trans OR optical</i> Level 1 (1–2 marks) Names and draws structures of two of the	6	Indicative scientific points may include: Shapes of complex ions • six coordinate bonds: octahedral • four coordinate bonds: tetrahedral or square planar • 3-D diagrams with charges linked to shapes  Octahedral  Tetrahedral  Square Planar cis–trans isomerism • found in octahedral and square planar complexes • <i>trans</i> – opposite; <i>cis</i> – adjacent / same side • 3-D diagrams to illustrate  <i>cis</i>  <i>trans</i> OR  <i>cis</i>  <i>trans</i> Optical isomerism • Found in octahedral complexes when bidentate ligands are present • Isomers are non-superimposable mirror images • 3-D diagrams to illustrate

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
	shapes AND Appreciates one type of isomerism that can be seen in transition metal chemistry. <i>The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.</i> <i>Answers question with a basic grasp of relevant technical language</i> - links octahedral to six ligands and tetrahedral to four ligands either in word or by diagram - correctly links one type of isomerism to a structure. 0 marks No response or no response worthy of credit.		 2+  2+ OR  2+  2+
	Total	15	

Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
8	a	Cr: $(1s^2 2s^2 2p^6) 3s^2 3p^6 3d^5 4s^1$ Cr³⁺: $(1s^2 2s^2 2p^6) 3s^2 3p^6 3d^3$	2	ALLOW 4s before 3d, ie $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^5$ ALLOW $1s^2$ written after answer prompt (ie $1s^2$ twice) ALLOW upper case D, etc and subscripts, e.g. $4S_1 3D_5$ ALLOW for Cr³⁺ $4s^0$ DO NOT ALLOW [Ar] as shorthand for $1s^2 2s^2 2p^6 3s^2 3p^6$ Look carefully at $1s^2 2s^2 2p^6 3s^2 3p^6$ – there may be a mistake.
	b	<i>Formula of complex ion J</i> Structures show correct ligands (4 NH₃ AND 2 Cl) AND 1+ charge (on at least one structure) <i>Stereoisomers</i>  <i>cis</i>  <i>trans</i> NOTE: For each structure, bonding from Co must be to N of NH₃ <i>cis</i> and <i>trans</i> labels required for both structure marks. If structures are correct but labels are wrong way round or omitted, award 1 out of the 2 stereoisomer marks. TAKE CARE: structures may be in different orientations.	3	FULL ANNOTATIONS MUST BE USED ----- For two stereoisomer marks, IGNORE charges (anywhere) Charge already credited within the 1st mark. Square brackets NOT required Must contain 2 'out wedges', 2 'in wedges' and 2 lines in plane of paper OR 4 lines, 1 'out wedge' and 1 'in wedge': For bond into paper, ALLOW:  ALLOW following geometry throughout: 

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c	i	A: $\text{Cr}_2(\text{SO}_4)_3$ B: MnI_2 State symbols not required in equations (within observations). C: $\text{Cr}^{3+} + 3\text{OH}^- \rightarrow \text{Cr}(\text{OH})_3$ D: $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 6\text{NH}_3 \rightarrow [\text{Cr}(\text{NH}_3)_6]^{3+} + 6\text{H}_2\text{O}$ E: $\text{Mn}^{2+} + 2\text{OH}^- \rightarrow \text{Mn}(\text{OH})_2$ F: $\text{Ba}^{2+} + \text{SO}_4^{2-} \rightarrow \text{BaSO}_4$ G: $\text{Ag}^+ + \text{I}^- \rightarrow \text{AgI}$	7	Formulae required in question IGNORE incorrect names IGNORE incorrect state symbols ALLOW $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 3\text{OH}^- \rightarrow \text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3 + 3\text{H}_2\text{O}$ ALLOW $\text{Cr}(\text{OH})_3(\text{H}_2\text{O})_3 + 6\text{NH}_3 \rightarrow [\text{Cr}(\text{NH}_3)_6]^{3+} + 3\text{H}_2\text{O} + 3\text{OH}^-$ ALLOW $[\text{Mn}(\text{H}_2\text{O})_6]^{2+} + 2\text{OH}^- \rightarrow \text{Mn}(\text{OH})_2(\text{H}_2\text{O})_4 + 2\text{H}_2\text{O}$
		ii	removes / reacts with carbonate / CO_3^{2-} AND carbonate forms a (white) precipitate	1	Both statements required for the mark Note: 2nd statement can be for Test 2 (Ba^{2+}) OR Test 3 (Ag^+)
		iii	Test 2: no difference Test 3 gives a white precipitate by reaction with Cl^- A: white precipitate AND B: white / yellow ppt OR cream ppt OR paler yellow ppt	3	
		iv	Add concentrated ammonia / NH_3 AND yellow precipitate does not dissolve	1	Concentrated essential for NH_3
			Total	17	

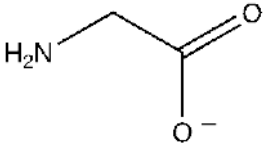
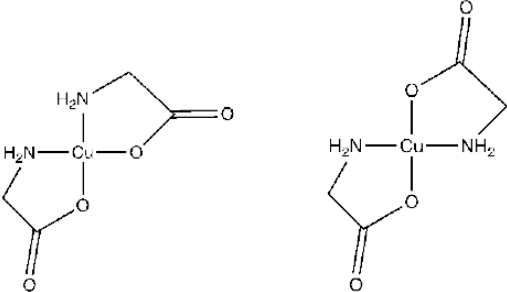
Mark Scheme

Question		Answer/Indicative content	Marks	Guidance
9	a	<i>* Please refer to the marking instruction point 10 for guidance on how to mark this question.</i> Level 3 (5–6 marks) Develops a plan that allows identification of all six ions AND includes essential detail and equations for all test procedures and observations, with three anion tests in the correct sequence, CO_3^{2-}, SO_4^{2-} then Cl^- AND includes cation test with essential detail and all equations <i>There is a well-developed, detailed plan which is clear and logically structured. The plan is substantiated with relevant information, e.g. justification of the sequence of anion tests. There is a clear explanation of how the observations allow the ions to be identified.</i> Level 2 (3–4 marks) Develops a plan that allows identification of at least three ions AND includes detail of at least three test procedures and observations, and three equations <i>There is an appropriate plan presented with some structure. Parts of the fine detail, correct sequence, or reference to use of both samples may be missing. There is some attempt to explain how the observations allow the ions to be identified.</i> Level 1 (1–2 marks) Develops a plan that allows identification of at least two ions AND includes detail of at least two test procedures and observations, and one equation <i>The plan is basic and communicated in an unstructured way. The response lacks fine</i>	6	Indicative scientific points may include: Use one sample for cation test, other sample for anion tests Details of tests <i>Cation test</i> add Aqueous sodium hydroxide Positive observations - for Mn^{2+}: pink / buff precipitate - for Fe^{2+}: green precipitate - for NH_4^+: litmus paper held over the opening of the tube turns blue Fine detail: (gentle) heating for NH_4^+ test Equations: $\text{Mn}^{2+} + 2\text{OH}^- \rightarrow \text{Mn}(\text{OH})_2$ $\text{Fe}^{2+} + 2\text{OH}^- \rightarrow \text{Fe}(\text{OH})_2$ $\text{NH}_4^+ + \text{OH}^- \rightarrow \text{NH}_3 + \text{H}_2\text{O}$ <i>Anion tests</i> CO_3^{2-}: - add nitric acid; positive observation: effervescence SO_4^{2-}: - add aqueous barium nitrate; positive observation: white precipitate Cl^-: - add silver nitrate solution; positive observation: white precipitate Fine detail for Cl^-: - subsequent addition of dilute ammonia solution positive observation: precipitate dissolves.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			<i>detail and no reference to correct sequence of anion tests. There is little or no attempt to explain how the observations allow the ions to be identified.</i> 0 marks No response or no response worthy of credit.		Fine detail: correct sequence of all three anion tests - carbonate test followed by sulfate test followed by halide test - justification of sequence ALLOW splitting of solution over three boiling tubes / test tubes and performing each test on a different sample. Equations: $\text{CO}_3^{2-} + \text{H}^+ \rightarrow \text{CO}_2 + \text{H}_2\text{O}$ $\text{Ba}^{2+} + \text{SO}_4^{2-} \rightarrow \text{BaSO}_4$ $\text{Ag}^+ + \text{Cl}^- \rightarrow \text{AgCl}$
	b	i	Co : N : H : Cl = $\frac{21.98}{58.9} : \frac{31.35}{14.0} : \frac{6.72}{1.0} : \frac{39.75}{35.5}$ = 0.373 : 2.24 : 6.72 : 1.12 = 1 : 6 : 18 : 3 Formula = $\text{CoN}_6\text{H}_{18}\text{Cl}_3$	2	
		ii	$[\text{Co}(\text{NH}_3)_6]^{3+}$	1	
			Total	9	
10	a	i	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^6$	1	
		ii	4	1	
	b		$[\text{Fe}(\text{CN})_6]^{3-}$ shown as product in equation Remaining species and balancing correct balanced equation: $[\text{Fe}(\text{H}_2\text{O})_6]^{3+} + 6\text{CN}^- \rightarrow [\text{Fe}(\text{CN})_6]^{3-} + 6\text{H}_2\text{O}$	2	Notice different charges on complex ions: LHS 3+, RHS 3– ALLOW equations with KCN, i.e.: $[\text{Fe}(\text{H}_2\text{O})_6]^{3+} + 6\text{KCN} \rightarrow [\text{Fe}(\text{CN})_6]^{3-} + 6\text{K}^+ + 6\text{H}_2\text{O}$ $[\text{Fe}(\text{H}_2\text{O})_6]^{3+} + 6\text{K}^+ + 6\text{CN}^- \rightarrow [\text{Fe}(\text{CN})_6]^{3-} + 6\text{K}^+ + 6\text{H}_2\text{O}$ state symbols not required
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
11		i		1	Must be skeletal formula
		ii		2	IGNORE charges ALLOW Cs and Hs labelled on structures <i>Marks are for correct connectivity</i>
		iii	Alanine has a chiral C atom / centre	1	
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
12	a	i	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$ ✓	1	ALLOW upper case S, P and D and subscripts, e.g. 3S₂3P₆3D₁₀ ALLOW 4s¹ before 3d¹⁰ DO NOT ALLOW [Ar] as shorthand for 1s²2s²2p⁶3s²3p⁶, i.e. DO NOT ALLOW [Ar]3d⁸ Look carefully at 1s²2s²2p⁶3s²3p⁶ – there may be a mistake
		ii	$n = \frac{95.0}{24000} = 3.96 \times 10^{-3} \text{ (mol)}$ ✓ <i>Calculation of M</i> $M = \frac{m}{n} = \frac{254 \times 10^{-3}}{3.96 \times 10^{-3}} = 64.2 \text{ OR } 64.1 \text{ (g mol}^{-1}\text{)}$ ✓ <i>Gas:</i> sulfur dioxide OR SO ₂ ✓ <i>Equation</i> $\text{Cu} + 2\text{H}_2\text{SO}_4 \rightarrow \text{CuSO}_4 + \text{SO}_2 + 2\text{H}_2\text{O}$ ✓	4	IF there is an alternative answer, check to see if there is any ECF credit possible using working below Unrounded values give 64.2; Rounded to 3 SF gives 64.1 ALLOW $\text{Cu} + 2\text{H}^+ + \text{H}_2\text{SO}_4 \rightarrow \text{Cu}^{2+} + \text{SO}_2 + 2\text{H}_2\text{O}$
	b	i	green solution: Fe²⁺(aq) OR [Fe(H₂O)₆]²⁺ AND gas bubbles: H₂(g) AND orange-brown solution: Fe³⁺(aq) OR [Fe(H₂O)₆]³⁺ ✓ Fe(s) + 2H⁺(aq) → Fe²⁺(aq) + H₂(g) ✓ 4Fe²⁺(aq) + O₂(g) + 4H⁺(aq) → 4Fe³⁺(aq) + 2H₂O(l) ✓	3	State symbols are not required in this part IGNORE, even if incorrect ALLOW full equation: $\text{Fe(s)} + 2\text{HCl(aq)} \rightarrow \text{FeCl}_2\text{(aq)} + \text{H}_2\text{(g)}$

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	orange solution: $\text{Cr}_2\text{O}_7^{2-}$ AND green solution (anywhere) Cr^{3+} OR $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$ ✓ $2\text{Cr}^{3+}(\text{aq}) + \text{H}_2\text{O}(\text{l}) + 3\text{H}_2\text{O}_2(\text{aq}) \rightarrow$ $\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 8\text{H}^+(\text{aq})$ H^+, H_2O and e^- all cancelled ✓✓	3	State symbols are not required in this part IGNORE, even if incorrect IGNORE $\text{Cr}(\text{VI})$ <i>The question asks for species</i> ALLOW 1 mark for $\text{H}^+/\text{H}_2\text{O}/\text{e}^-$ not cancelled, e.g. $2\text{Cr}^{3+}(\text{aq}) + 7\text{H}_2\text{O}(\text{l}) +$ $3\text{H}_2\text{O}_2(\text{aq}) + 6\text{H}^+(\text{aq}) \rightarrow \text{Cr}_2\text{O}_7^{2-}(\text{aq}) +$ $14\text{H}^+(\text{aq}) + 6\text{H}_2\text{O}(\text{l})$ ✓
			Total	11	

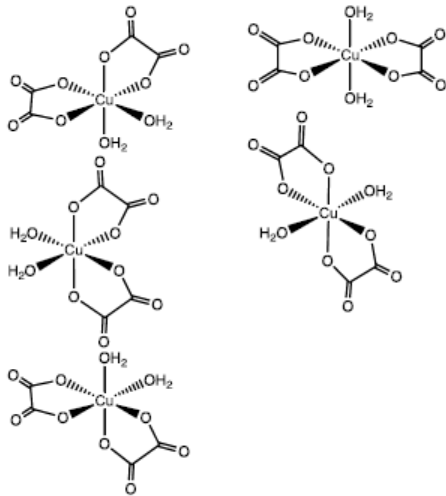
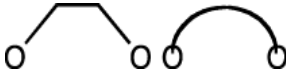
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
13	a		IGNORE any charges shown within complexes (treat as rough working) Formulae 2 marks $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ ✓ $[\text{CuCl}_4]^{2-}$ ✓ Colours blue AND yellow ✓ <i>Mark independently of formulae</i> 1 mark	3	For charges, ALLOW +2 and -2 Square brackets required, i.e. DO NOT ALLOW $\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2^{2+}$ ALLOW Ligands in any order ALLOW CuCl_4^{2-} i.e. no brackets OR $\text{Cu}(\text{Cl})_4^{2-}$ For CuCl_4^{2-}, ALLOW green—yellow OR yellow—green DO NOT ALLOW green For $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ DO NOT ALLOW pale blue, light blue DO NOT ALLOW precipitate with blue OR yellow Examiner's Comments This question assessed complex ions of transition elements. Although a relatively gentle introduction to the paper, the question discriminated well. This question required knowledge and understanding of complex ions formed in ligand substitution reactions of aqueous Cu^{2+} ions. Well-prepared candidates usually collected the three marks with comparative ease. For the complex ions, common errors included $[\text{Cu}(\text{NH}_3)_6]^{2+}$ instead of $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ and incorrect charges (e.g. CuCl_4^-). The observations were well known although green, rather than yellow, was often seen for CuCl_4^{2-}.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	b	i	Donates two electron pairs to a metal ion / metal / Cu^{2+} AND forms two coordinate bonds to a metal ion / metal / Cu^{2+} ✓	1	ALLOW lone pairs for electron pairs ALLOW molecule / atom / ion / substance for 'ligand' ALLOW dative (covalent) bonds for coordinate bonds ALLOW transition element for metal Two is needed once only e.g. Donates two electron pairs to form coordinate bonds to a metal ion / metal / Cu^{2+} Donates electron pairs to form two coordinate bonds to a metal ion / metal / Cu^{2+} DO NOT ALLOW donates two electron pairs to form one / a coordinate bond Examiner's Comments This question assessed complex ions of transition elements. Although a relatively gentle introduction to the paper, the question discriminated well. Most candidates obtained this mark in terms of donation by two electron pairs to a metal ion to form two coordinate or dative covalent bonds. Some candidates omitted donation, reference to a metal ion, or the formation of coordinate bonds.

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
ii		3	FULL ANNOTATIONS MUST BE USED 2 marks: one for each correct isomer ✓ ✓ TAKE CARE: structures may be in different orientations and in different order IF BOTH isomers are 'correct', but O connectivity wrong, AWARD 1 mark for both structures Check H₂O ligands carefully for connectivity ALLOW H₂O reversed shown as — O₂H IGNORE charges (anywhere) ----- NOTE: For each structure, ALL O atoms must be shown AND For (COO⁻)₂, ALLOW skeletal, structural or displayed formula DO NOT ALLOW structures such as those shown below  -----

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance						
		ii	<table><tr><td><i>cis</i></td><td>✓</td></tr><tr><td><i>trans</i></td><td></td></tr><tr><td>optical</td><td>✓</td></tr></table>	<i>cis</i>	✓	<i>trans</i>		optical	✓		1 mark: for whole of 2nd row for whole of 'Type' row i.e. (cis AND optical) AND trans only Examiner's Comments This question assessed complex ions of transition elements. Although a relatively gentle introduction to the paper, the question discriminated well. Candidates were required to draw accurate diagrams of stereoisomers of $[\text{Cu}(\text{COO})_2(\text{H}_2\text{O})_2]^{2-}$ and to classify these. The examiners were impressed with the accuracy of the diagrams seen. The inclusion of a 3D template and structure of one of the stereoisomers gave candidates a good indication of what was required. Unfortunately, marks were lost by showing the same stereoisomer twice, omitting O atoms from the COO^{2-} ligands or poor connectivity of the H_2O ligands. Many candidates did not identify one of the stereoisomers as being both <i>cis</i> and optical.
<i>cis</i>	✓										
<i>trans</i>											
optical	✓										

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	$\text{CuC}_4\text{H}_4\text{O}_{10}^{2-}$ Formula ✓ 2— charge ✓ MARK formula and charge INDEPENDENTLY	2	Empirical formula essential, e.g. DO NOT ALLOW $\text{Cu}(\text{COO})_2(\text{H}_2\text{O})_2$ for formula mark ALLOW any order of elements in formula ALLOW – 2 for charge Examiner's Comments This question assessed complex ions of transition elements. Although a relatively gentle introduction to the paper, the question discriminated well. In the formula, the majority of candidates showed the correct 2– charge but many failed to show an empirical formula. The main problem was use of a structural formula instead of the empirical formula: $\text{CuC}_4\text{H}_4\text{O}_{10}$. Candidates showing an empirical formula often omitted one of the ligand atoms, with C the commonest omission. The number of each atom also proved problematic, especially the O atoms.
			Total	9	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
14		i	IGNORE any charges shown within complexes (treat as rough working) Complex ion C: $[\text{Ni}(\text{H}_2\text{O})_6]^{2+}$ ✓ Solid D: $\text{Ni}(\text{OH})_2$ ✓ Complex ion E: $[\text{Ni}(\text{CN})_4]^{2-}$ ✓	3	ALLOW +2 and –2 for charges Square brackets required ALLOW $\text{Ni}(\text{H}_2\text{O})_4(\text{OH})_2$ $(\text{H}_2\text{O})_4$ and $(\text{OH})_2$ in any order IGNORE any square brackets Square brackets required TAKE CARE for round brackets within complex ion, i.e. (H_2O), (OH) and (CN) Examiner's Comments The majority of candidates obtained all three marks. Where marks were lost, it was often for missing or incorrect charges (e.g. $[\text{Ni}(\text{CN})_4]^{2+}$), and poor use of brackets (e.g. $\text{Ni}(\text{OH})_2$ and $[\text{NiCN}_4]^{2+}$). $\text{Ni}(\text{OH})_2(\text{H}_2\text{O})_4$ was often seen and was credited.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	Mark independently of 7(a)(i) ALLOW +2 and –2 for charges IGNORE any charges shown within complexes (treat as rough working) $\text{Ni}^{2+} + 2\text{OH}^- \rightarrow \text{Ni}(\text{OH})_2$ ✓ Type of reaction: precipitation ✓ INDEPENDENT of equation $[\text{Ni}(\text{H}_2\text{O})_6]^{2+} + 4\text{CN}^- \rightarrow [\text{Ni}(\text{CN})_4]^{2-} + 6\text{H}_2\text{O}(\text{l})$ ✓ Type of reaction: ligand substitution ✓ INDEPENDENT of equation	4	For equations: IGNORE state symbol (even if wrong) Square brackets not required for $\text{Ni}(\text{OH})_2$ ALLOW $[\text{Ni}(\text{H}_2\text{O})_6]^{2+} + 2\text{OH}^- \rightarrow [\text{Ni}(\text{H}_2\text{O})_4(\text{OH})_2] + 2\text{H}_2\text{O}$ ALLOW $[\text{Ni}(\text{H}_2\text{O})_6]^{2+} + 2\text{OH}^- \rightarrow \text{Ni}(\text{OH})_2 + 6\text{H}_2\text{O}$ ALLOW $\text{NiSO}_4(\text{aq}) + 2\text{OH}^-(\text{aq}) \rightarrow \text{Ni}(\text{OH})_2(\text{s}) + \text{SO}_4^{2-}(\text{aq})$ ALLOW $\text{NiSO}_4(\text{aq}) + 2\text{KOH}(\text{aq}) \rightarrow \text{Ni}(\text{OH})_2(\text{s}) + \text{K}_2\text{SO}_4(\text{aq})$ ALLOW acid / base OR neutralisation OR deprotonation ONLY IF $[\text{Ni}(\text{H}_2\text{O})_6]^{2+}$ AND $[\text{Ni}(\text{H}_2\text{O})_4(\text{OH})_2]$ used ALLOW precipitate ALLOW $[\text{Ni}(\text{H}_2\text{O})_6]^{2+} + 4\text{KCN} \rightarrow [\text{Ni}(\text{CN})_4]^{2-} + 6\text{H}_2\text{O} + 4\text{K}^+$ LOOK at formulae for E from 7(a)(i) (copied at bottom) ALLOW ECF in 7a(ii) Equation for no round brackets around CN, i.e. $[\text{NiCN}_4]^{2-}$ in 7a(i) This is the only ECF allowed from 7a(i) structures. ALLOW ligand exchange Examiner's Comments Provided that correct formulae had been obtained in (a)(i), correct equations often followed, although marks were again lost by careless uses of charge and brackets, and unbalanced equations. The types of reaction were usually correct.
			Total	7	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
15	a		Cu^{2+}: $(1s^2) 2s^2 2p^6 3s^2 3p^6 3d^9$ ✓ Cu^+: $(1s^2) 2s^2 2p^6 3s^2 3p^6 3d^{10}$ ✓	2	IGNORE repeated $1s^2$ after $1s^2$ prompt on answer line ALLOW $4s^0$, either before or after 3d ALLOW upper case D, etc and subscripts, e.g.....3S₂3P⁶ DO NOT ALLOW [Ar] as shorthand for $1s^2 2s^2 2p^6 3s^2 3p^6$ Examiner's Comments The responses seen were very mixed. Able candidates scored the two marks easily but many errors were seen, particularly by removal of 3d electrons rather than 4s electrons from copper atoms to give the electron configurations of the ions (especially for Cu^+ in CuI).
	b		IGNORE any charges shown within formulae (treat as rough working) $\text{CuCO}_3 + 2\text{HCOOH} \rightarrow \text{Cu}(\text{HCOO})_2 + \text{H}_2\text{O} + \text{CO}_2$ OR $\text{CuO} + 2\text{HCOOH} \rightarrow \text{Cu}(\text{HCOO})_2 + \text{H}_2\text{O}$ OR $\text{Cu}(\text{OH})_2 + 2\text{HCOOH} \rightarrow \text{Cu}(\text{HCOO})_2 + 2\text{H}_2\text{O}$ ✓	1	IGNORE state symbols In formula of HCOOH / HCOO, ALLOW H, C and O in ANY order ALLOW H_2CO_3 for H_2O and CO_2 in carbonate equation ALLOW $(\text{HCOO})_2\text{Cu}$ for $\text{Cu}(\text{HCOO})_2$ DO NOT ALLOW equation with CuSO_4 Examiner's Comments Most candidates attempted an equation using CuO, $\text{Cu}(\text{OH})_2$ or CuCO_3. Marks were then sometimes lost by not balancing the equation. It was not uncommon to see equations using CuSO_4 or CuCl_2 as reactant and consequently this mark was often not awarded.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		$2\text{Cu}^{2+} + 4\text{I}^{-} \rightarrow 2\text{CuI}(\text{s}) + \text{I}_2$ ✓ State symbol for CuI(s) ONLY required	1	ALLOW multiples, e.g. $\text{Cu}^{2+} + 2\text{I}^{-} \rightarrow \text{CuI}(\text{s}) + \frac{1}{2}\text{I}_2$ IGNORE other state symbols, even if incorrect Examiner's Comments This equation proved to be much more difficult than in 8(b), with only the best candidates producing a correctly balanced equation. As with 4(c) and 7(b)(iii), equations were often unbalanced in terms of charge and oxidation number.
	d		Starch ✓ Blue / black to colourless / white ✓ MARK INDEPENDENTLY	2	IGNORE 'brown' in composite colour with blue or black, i.e. ALLOW blue / brown to colourless ALLOW black / brown to colourless DO NOT ALLOW just 'it turns colourless / is decoloured' <i>Initial colour required</i> IGNORE clear for colourless Examiner's Comments Most candidates seemed unaware that starch is used to identify the end point in iodine–thiosulfate titrations. Even when starch was given, the colour change was often incorrect. Random responses were seen to this part, e.g. methyl orange, phenolphthalein, potassium manganate and sodium thiosulfate.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	e		WORKING REQUIRED Correct answer: $x = 4$ required evidence of working ----- $n(\text{S}_2\text{O}_3^{2-}) \text{ OR } n(\text{Cu}^{2+}) = \frac{0.0420 \times 23.5}{1000} = 9.87 \times 10^{-4} \text{ (mol) } \checkmark$ In 250.0 cm^3 solution, $n(\text{Cu}^{2+}) = 9.87 \times 10^{-3}$ (mol) $\checkmark$ $M(\text{Cu}(\text{HCOO})_2 \cdot 4\text{H}_2\text{O}) = \frac{2.226}{9.87 \times 10^{-3}} = 225.5 \text{ (g mol}^{-1}\text{)} \checkmark$ $x(\text{H}_2\text{O})$ has mass of $225.5 - M(\text{Cu}(\text{HCOO})_2)$ $= 225.5 - 153.5$ $= 72(.0) \checkmark$ $x = \frac{72(.0)}{18(.0)} = 4$ WHOLE NUMBER needed AND evidence of working $\checkmark$	5	FULL ANNOTATIONS MUST BE USED ----- At least 3 SF required throughout <i>Alternative approach for final 3 marks based on mass:</i> mass $\text{Cu}(\text{HCOO})_2 = 9.87 \times 10^{-3} \times 153.5 = 1.515 \text{ g } \checkmark$ $n(\text{H}_2\text{O}) = \frac{2.226 - 1.515}{18(.0)} = \frac{0.711}{18(.0)} = 0.0395 \text{ (mol) } \checkmark$ $x = \frac{0.0395}{9.87 \times 10^{-3}} = 4 \checkmark$ ALLOW $\text{Cu}(\text{HCOO})_2 \cdot 4\text{H}_2\text{O}$ ----- COMMON ERRORS for 4 marks $x = 117$ (calc 116.78) <i>Use of 9.87×10^{-4} (no scaling $\times 10$) $\rightarrow M = 2255.319$</i> $x = 17$ (calc 16.53) 4 marks <i>Use of 4.935×10^{-4} (Use of $0.5 \times 9.87 \times 10^{-3}$)</i> Check $n(\text{Cu}^{2+})$ for other ECFs Check for ECFs from incorrect $M(\text{anhydr salt})$ Actual = 153.5 Examiner's Comments Many candidates were on firm territory with a redox titration problem. The majority went through a well-rehearsed sequence of steps to obtain all five marks for showing that x was 4. Where '4' had not been obtained, marks could still be awarded for intermediate working if correct. Answer: $x = 4$
			Total	11	

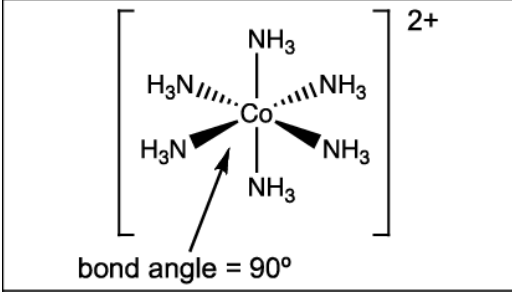
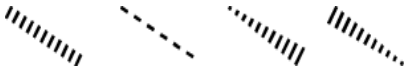
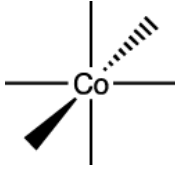
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
16			B	1	
			Total	1	
17			C	1	
			Total	1	
18		i	$3 \text{MnO}_4^{2-} + 4 \text{H}^+ \rightarrow 2 \text{MnO}_4^- + \text{MnO}_2 + 2 \text{H}_2\text{O}$ ✓	1	ALLOW 1 in front of MnO_2
		ii	In acidic conditions (Concentration of) H^+ increases AND equilibrium (position) shifts to the right to reduce concentration of H^+/remove H^+ ✓ In alkaline conditions OH^- reacts with H^+ AND equilibrium (position) shifts to the left to increase concentration of H^+/add H^+ ✓	2	ALLOW $\text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O}$
			Total	3	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
19	a	i	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^6$ ✓ Look carefully at $1s^2 2s^2 2p^6 3s^2 3p^6$ – there may be a mistake	1	ALLOW $4s^0$ before or after 3d, i.e. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^0 3d^6$ DO NOT ALLOW [Ar] as shorthand for $1s^2 2s^2 2p^6 3s^2 3p^6$ ALLOW upper case D, etc and subscripts, e.g. 3D ₁₀ IGNORE an extra $1s^2$ after prompt on answer line
		ii	$FeCl_4^-$ ✓ $\uparrow$ Conc HCl(aq) $[Fe(H_2O)_6]^{3+}$ pale yellow solution KI/I^- ✓ $\downarrow$ $\uparrow$ $(H^+)/MnO_4^-$ ✓ $[Fe(H_2O)_6]^{2+}$ pale green solution $\downarrow$ NaOH(aq) $Fe(OH)_2$ AND green precipitate ✓	4	Check correct 1– charge ALLOW brackets, e.g. $[FeCl_4]^-$ For I^- , ALLOW SO_2 , $(H^+)/Zn$ For MnO_4^- , ALLOW H_2O_2 , $(H^+)/Cr_2O_7^{2-}$, Cl_2 For $Fe(OH)_2$ ALLOW $Fe(OH)_2(H_2O)_4$ For colour, ALLOW any colour that describes green
	b	i	$[Co(H_2O)_6]^{2+} + 6NH_3 \rightarrow [Co(NH_3)_6]^{2+} + 6H_2O$ ✓ ligand substitution ✓	2	ALLOW ligand exchange

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
ii	 3 -D Shape ✓ bond angle 90 ° ✓ Bonds must be to N of NH₃ ligands	2	IGNORE charges (anywhere) and labels (even if wrong) Square brackets NOT required Must contain 2 'out wedges', 2 'in wedges' and 2 lines in plane of paper OR 4 lines, 1 'out wedge' and 1 'in wedge': For bond into paper, ALLOW:  ALLOW following geometry throughout: 
iii	Empirical formula of complex D $\begin{array}{cccc} \text{Co} & : & \text{N} & : & \text{H} & : & \text{Cl} \\ \hline 22.03 & : & 31.41 & : & 6.73 & : & 39.83 \\ 58.9 & : & 14.0 & : & 1.00 & : & 35.5 \end{array}$ OR 0.374 : 2.24 : 6.73 : 1.12 ✓ = 1 : 6 : 18 : 3 = CoN₆H₁₈Cl₃ ✓ complex ion C [Co(NH₃)₆]³⁺ ✓ complex D [Co(NH₃)₆]³⁺[Cl]₃ ✓	4	Correct empirical formula subsumes previous mark ALLOW [Co(NH₃)₆]³⁺ 3Cl⁻

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iv	Half equations $[\text{Co}(\text{NH}_3)_6]^{2+} \rightarrow [\text{Co}(\text{NH}_3)_6]^{3+} + \text{e}^-$ ✓ $\text{H}_2\text{O}_2 + 2\text{e}^- \rightarrow 2\text{OH}^-$ ✓ Overall equation $2[\text{Co}(\text{NH}_3)_6]^{2+} + \text{H}_2\text{O}_2 \rightarrow 2[\text{Co}(\text{NH}_3)_6]^{3+} + 2\text{OH}^-$ ✓	1	ALLOW multiples throughout ALLOW $\text{H}_2\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightarrow 2\text{H}_2\text{O}$ ALLOW $2[\text{Co}(\text{NH}_3)_6]^{2+} + \text{H}_2\text{O}_2 + 2\text{H}^+ \rightarrow 2[\text{Co}(\text{NH}_3)_6]^{3+} + 2\text{H}_2\text{O}$
			Total	16	
20		i	$1\text{s}^2 2\text{s}^2 2\text{p}^6 3\text{s}^2 3\text{p}^6 3\text{d}^6$ ✓	1	
		ii	$[\text{Fe}]^{2+}$ - Electrons for each S atom must be shown differently, e.g. • for left-hand S and × for right hand S - Two 'extra' electrons shown with different symbol (as a square in diagram above) with one square on each S atom. MARKING 1 covalent bond between two S atoms with • AND × ✓ Rest of structure correct including 2 extra electrons ✓	2	IGNORE any outer electrons shown on Fe Electrons donated by Fe must be different. ALLOW dative covalent bond for covalent bond using two dots OR 2 crosses for 1st mark 2nd mark will then have the 2 extra electrons on the S atom that has donated the electrons for the dative covalent bond.
			Total	3	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
21	a		$n(\text{H}_2\text{O}) = 27.55/18.0 = 1.5306 \text{ (mol)} \checkmark$ $n((\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2) = 72.45/284.0 = 0.2551 \text{ (mol)} \checkmark$ whole number ratio of $(\text{NH}_4)_2\text{Fe}(\text{SO}_4)_2$: H_2O $= 0.2551 : 1.5306 = 1 : 6$ OR $x = 6 \checkmark$	3	If there is an alternative answer, check to see if there is any ECF credit possible ALLOW calculator value or rounding to two significant figures or more but IGNORE 'trailing zeroes' if wrong <i>M</i> produces such numbers throughout. ALLOW ECF If no working, ALLOW 1 mark for $x = 6$.
	b	i	To neutralise acidic soil $\checkmark$	1	

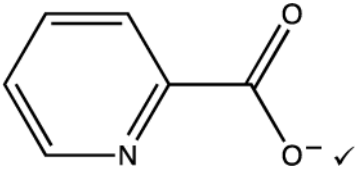
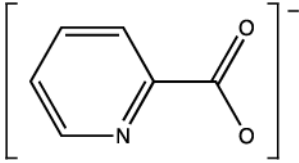
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	<i>Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question.</i> Level 3 (5–6 marks) Describes practical details of tests and observations that allows all four ions to be identified AND Attempts associated equations, with most correct. <i>There is a well-developed line of reasoning and the method is clear and logically structured. The information presented is relevant and substantiated by observations from the tests described and practical details.</i> Level 2 (3–4 marks) Describes most practical details of tests including the observations that allows most ions to be identified AND Attempts associated equations, with some correct. <i>There is a line of reasoning presented and the method has some structure. The information presented is in the most-part relevant and supported by some evidence of observations from the tests described but practical details may be absent.</i> Level 1 (1–2 marks) Describes some of the practical details of tests and observations would only allow some ions to be identified. OR Attempts associated equations, with some correct. <i>The information is basic and the method lacks structure. The information is supported by limited evidence of the observations, the relationship to the evidence may not be clear.</i> 0 marks No response or no response	6	Indicative scientific points may include Practical details: • Sample stirred with water and mixture filtered. • SO_4^{2-}, Fe^{2+}, NH_4^+ tests on filtrate. • CO_3^{2-} test on residue or garden product Tests and associated equations: CO_3^{2-} test: Test: Add nitric acid. Observation: effervescence. Equation: $\text{CaCO}_3 + 2\text{H}^+ \rightarrow \text{Ca}^{2+} + \text{CO}_2 + \text{H}_2\text{O}$ ALLOW $\text{CO}_3^{2-} + 2\text{H}^+ \rightarrow \text{CO}_2 + \text{H}_2\text{O}$ OR overall equation of CaCO_3 and an acid. SO_4^{2-} test: Add $\text{BaCl}_2(\text{aq})/\text{Ba}(\text{NO}_3)_2(\text{aq})/\text{Ba}^{2+}(\text{aq})$. Observation: white precipitate. Equation: $\text{Ba}^{2+} + \text{SO}_4^{2-} \rightarrow \text{BaSO}_4$ Fe^{2+} test: Test: Add $\text{NaOH}(\text{aq})$ Observation: green precipitate Equation: $\text{Fe}^{2+} + 2\text{OH}^- \rightarrow \text{Fe}(\text{OH})_2$ NH_4^+ test: Test: Add $\text{NaOH}(\text{aq})$ and warm Observation: gas turns red litmus indicator blue Equation: $\text{NH}_4^+ + \text{OH}^- \rightarrow \text{NH}_3 + \text{H}_2\text{O}$

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			worthy of credit.		
	c	i	Equation: $\text{Cu}^{2+}(\text{aq}) + 2\text{OH}^{-}(\text{aq}) \rightarrow \text{Cu}(\text{OH})_2(\text{s})$ ✓ <i>State symbols required</i> Observation: Blue precipitate ✓	2	ALLOW $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}(\text{aq}) + 2\text{OH}^{-}(\text{aq}) \rightarrow \text{Cu}(\text{H}_2\text{O})_4(\text{OH})_2(\text{s}) + 2\text{H}_2\text{O}(\text{l})$ ALLOW blue solid
		ii	Coordinate/dative covalent bonds between protein and Cu^{2+}/Cu ✓ N atoms OR O atoms in protein donate electron pairs ✓	2	
			Total	14	
22			D	1	
			Total	1	
23			D	1	
			Total	1	
24			A	1	
			Total	1	
25			B	1	
			Total	1	

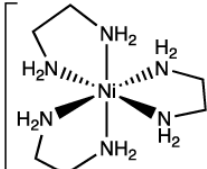
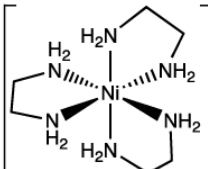
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
26		i		1	ALLOW brackets around structure with negative charge outside, i.e.  ALLOW ring (Kekulé structure) Examiner's Comment: Most candidates identified the skeleton of the ligand. However, this was often drawn without the minus sign on the COO⁻ or with an additional minus sign on the nitrogen.
		ii	FIRST CHECK THE ANSWER ON THE ANSWER LINE If answer = 1.61×10^{-3} award 2 marks $M = 418(.0) \text{ (g mol}^{-1}\text{)} \text{ OR } n(\text{Cr}) = 3.85 \times 10^{-6} \text{ (mol)} \checkmark$ Mass = $3.85 \times 10^{-6} \times 418.0 = 1.61 \times 10^{-3} \text{ g} \checkmark$	2	Note: $\frac{200 \times 10^{-6}}{52.0} = 3.85 \times 10^{-6}$ (at least 3 SF) ALLOW ECF from incorrect M OR $n(\text{Cr})$ ALLOW 3 SF up to calculator value correctly rounded For 5a(i)–(iv) IGNORE poor connectivity to SH groups <i>Given in question</i> Examiner's Comment: Most candidates calculated the amount of chromium correctly as $3.85 \times 10^{-6} \text{ mol}$. The second mark required this value to be multiplied by the molar mass of the complex. Success here was dependent on obtaining the correct molar mass of 418 g mol^{-1}. Candidates scored better here than in 4(c)(i). Answer: $1.61 \times 10^{-3} \text{ g}$
			Total	3	

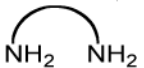
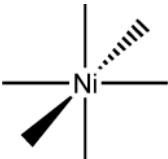
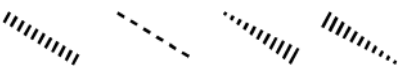
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
27	a	i	CuCl_4^{2-} OR $[\text{CuCl}_4]^{2-}$ ✓ yellow solution $\text{Cu}(\text{OH})_2$ ✓ pale blue precipitate $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ ✓ deep blue solution CuI ✓ I_2 ✓ white solid brown solution	5	ALLOW $\text{Cu}(\text{Cl})_4^{2-}$ ALLOW $\text{Cu}(\text{OH})_2(\text{H}_2\text{O})_4$ Brackets required for $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ NOTE: Take great care to check that subscripted numbers and brackets are correct Examiner's Comments The identification and recall of transition element compounds and ions was not done well. Most candidates knew the yellow solution to be CuCl_4^{2-} and the majority suggested the brown solution was I_2. The formula of the blue precipitate $\text{Cu}(\text{OH})_2$ was less well known and only a small minority were able to identify the deep blue solution and white solid as $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ and CuI respectively.
		ii	Reaction 1: ligand substitution ✓ Reaction 2: redox ✓	2	ALLOW ligand exchange ALLOW reduction AND oxidation ALLOW precipitation Examiner's Comments Ligand substitution was well known but redox was less frequently seen. However, as reaction 2 formed a precipitate, precipitation was accepted as an alternative answer.

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
b	<i>Please refer to the marking instructions on page 5 of this mark scheme for guidance on how to mark this question.</i> Level 3 (5–6 marks) A comprehensive conclusion using all data to obtain correct formulae for A, B, C and D AND optical isomers shown <i>There is a well-developed line of reasoning which is clear and logically structured with use of 3D structures for both optical isomers of C, use of wedges and bonding to N.</i> <i>The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Reaches a sound conclusion for the formula of B AND obtains the correct formula of the hydrated complex A OR a 3D diagram of one optical isomer of cation C <i>There is a line of reasoning and supported by some evidence. Calculations are clear and can be followed to obtain correct conclusions. 3D diagram, if present, should use wedges mostly correctly.</i> <i>Formula of A to show water separately or formula of C to show ligands separately, as appropriate.</i> Level 1 (1–2 marks) Reaches a simple conclusion to obtain the correct formula of anhydrous complex B OR shows that A contains 2H₂O <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant. Attempts more than one part of the problem.</i>	6	Indicative scientific points may include: 1. Formula of anhydrous complex B NiC₆N₆H₂₄Cl₂ <i>Example of working</i> $= \frac{18.95}{58.7} : \frac{23.25}{12.0} : \frac{27.12}{14.0} : \frac{7.75}{1.00} : \frac{22.93}{35.5}$ <i>There may be other methods</i> 2. Formula of hydrated complex A NiC₆N₆H₂₄Cl₂•2H₂O OR NiC₆N₆H₂₄Cl₂(H₂O)₂ <i>Example of working</i> $n(\text{anhydrous salt}) = \frac{7.433}{309.7} = 0.02400 \text{ (mol)}$ $n(\text{H}_2\text{O}) = \frac{0.864}{18.0} = 0.04800 \text{ (mol)} \checkmark$ <i>There may be other methods</i> 3. Formula of cation C [NiC₆N₆H₂₄]²⁺ OR [Ni(H₂NCH₂CH₂NH₂)₃]²⁺ <i>(could be in structures)</i> 2+ charge can be shown on cation OR optical isomers (i.e. seen somewhere) • Bidentate ligand D H₂NCH₂CH₂NH₂ or displayed so that structure is clearly unambiguous. • Optical isomers   <i>Accuracy of structures</i>

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			0 marks No response or no response worthy of credit.		Bonding shown from Ni to N of $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$ ALLOW $\text{CH}_3\text{CH}(\text{NH}_2)_2$ for ligand For $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$ in optical isomers, ALLOW C–C without Hs and  Each structure to contain 2 'out wedges', 2 'in wedges' and 2 lines in plane of paper OR 4 lines, 1 'out wedge' and 1 'in wedge':  Bond into paper can be shown as:  Examiner's Comments This was the second extended response question. Most candidates were able to make a start on this response and found the formula of B. A significant number of candidates assumed the bidentate ligand D to be $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$ and worked backwards to identify C. Having identified C, the drawing of optical isomers proved relatively straightforward. Many strong candidates omitted to determine the formula of A or realised quite late on within their extended response that this was required.
			Total	13	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
28			D	1 (AO 1.1)	<u>Examiner's Comments</u> The drawing of many (incorrect) shapes based upon a tetrahedral arrangement around the central Pt ion suggested many were unaware of the square planar shape of the complex.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
29	a		Ni: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^8 4s^2$ ✓ Ni²⁺: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^8$ ✓	2	ALLOW 4s before 3d, ie $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^8$ ALLOW 1² written after answer prompt (ie 1s² twice) ALLOW upper case D, etc and subscripts, e.g. 4S₂3D₈ ALLOW for Ni²⁺ 4s0 DO NOT ALLOW [Ar] as shorthand for $1s^2 2s^2 2p^6 3s^2 3p^6$ Look carefully at $1s^2 2s^2 2p^6 3s^2 3p^6$ – there may be a mistake <u>Examiner's Comments</u> Most candidates knew the electron configuration of an Ni atom but the number knowing the electron configuration of the Ni²⁺ ion was considerably fewer. The common error was the failure to remove the two 4s electrons.

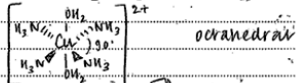
Mark Scheme

Question		Answer/Indicative content	Marks	Guidance																					
b		<i>Please refer to the marking instructions on page 5 of this mark scheme for guidance on how to mark this question.</i> Level 3 (5–6 marks) All three reactions are covered in detail with C, D, E and F identified with clear explanations. <i>There is a well-developed line of reasoning which is clear and logically structured with clear chemical communication and few omissions. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) All three reactions are covered but explanations may be incomplete OR Two reactions are explained in detail. <i>There is an attempt at a logical structure with a line of reasoning. The information is relevant e.g. formulae may contain missing brackets or numbers and supported by some evidence.</i> Level 1 (1–2 marks) Make two simple explanations from any one reaction. OR Makes one simple explanation from each of two reactions <i>There is an attempt at a logical structure with a line of reasoning The information is in the most part relevant.</i> 0 marks No response worthy of credit.	6	Indicative scientific points may include: REACTION 1 (CuSO₄/NH₃) <i>Product</i> C : [Cu(NH₃)₄(H₂O)₂]²⁺ <i>Equation</i> [Cu(H₂O)₆]²⁺ + 4NH₃ → [Cu(NH₃)₄(H₂O)₂]²⁺ + 4H₂O <i>Structure of trans stereoisomer</i> Correct connectivity REACTION 2 (Cu₂O/H₂SO₄) <i>Products</i> D : CuSO₄ OR [Cu(H₂O)₆]²⁺ E: Cu <i>Equation</i> Cu₂O + H₂SO₄ → CuSO₄ + Cu + H₂O <i>Oxidation numbers</i> Cu(+1) → Cu(+2) + Cu(0) REACTION 3 (CuO/HNO₃) <i>Equation</i> CuO + 2HNO₃ → Cu(NO₃)₂ + H₂O <i>Molar ratios</i> <table><tr><td>Cu</td><td>:</td><td>H</td><td>:</td><td>N</td><td>:</td><td>O</td></tr><tr><td>26.29</td><td>:</td><td>2.49</td><td>:</td><td>11.59</td><td>:</td><td>59.63</td></tr><tr><td>63.5</td><td>:</td><td>1.0</td><td>:</td><td>14.0</td><td>:</td><td>16.0</td></tr></table> <i>Formula of F</i> CuH₆N₂O₉ F: Cu(NO₃)₂•3H₂O (OR Cu(NO₃)₂(H₂O)₃) Further guidance on use of wedges - Must contain 2 ‘out wedges’, 2 ‘in wedges’ and 2 lines in plane of paper OR 4 lines, 1 ‘out wedge’ and 1 ‘in wedge’: - For bond into paper, ALLOW: ALLOW following geometry:	Cu	:	H	:	N	:	O	26.29	:	2.49	:	11.59	:	59.63	63.5	:	1.0	:	14.0	:	16.0
Cu	:	H	:	N	:	O																			
26.29	:	2.49	:	11.59	:	59.63																			
63.5	:	1.0	:	14.0	:	16.0																			

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
			<u>Examiner's Comments</u> Many candidates had a stab at identifying C–F but neglected to include equations for the three reactions described or to show relevant working. Most candidates recognised C as the ammoniacal copper(II) ion but the formula was frequently incorrect and correct attempts at a ligand substitution equation from $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ was rarely seen. Diagrams showing the <i>trans</i> isomer were attempted but often of poor quality due to incorrect linking. Candidates recognised D as being CuSO_4 but often did not identify E as Cu due to a lack of familiarity with this common disproportionation reaction. $\text{Cu}(\text{OH})_2(\text{s})$ was a common incorrect identification of E. Only the best responses described the oxidation number changes which made this a disproportionation reaction. F was identified by a percentage by mass calculation to determine an empirical formula and then by deduction to produce $\text{Cu}(\text{NO}_3)_2 \cdot 3\text{H}_2\text{O}$. Having done this, many candidates did not give the relatively simple equation for reaction 3 between copper(II) oxide and dilute nitric acid.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance																				
					Exemplar 2 (d)* 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, G, which is a <i>trans</i> isomer. $\Rightarrow 100$ 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] ① $[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 4H_2O$  This is the <i>trans</i> isomer [C] because the H_2O ligands are 180° apart. ② $Cu_2O + H_2SO_4(aq) \rightarrow Cu_2O + CuSO_4(aq) + H_2O(l)$ brown solid blue solution [E] [D] [NOTE] ③ $CuO + 2HNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + H_2O(l)$ <table><tr><td></td><td>Cu</td><td>H</td><td>N</td><td>O</td></tr><tr><td>mass</td><td>26.29</td><td>2.48</td><td>11.59</td><td>59.63</td></tr><tr><td>rfm</td><td>63.5</td><td>1</td><td>14</td><td>16</td></tr><tr><td>mol</td><td>0.414</td><td>2.48</td><td>0.828</td><td>3.73</td></tr></table> Additional answer space if required. $1 : 6 : 2 : 9$ $\Rightarrow CuH_6N_2O_9$ A hydrated salt is made up of an anhydrous salt with water of crystallisation. $Cu(NO_3)_2 \cdot 3H_2O$ [F] and molecular. $\Rightarrow$ This fits the empirical formula. NOTE: ② The oxidation number of Cu goes from +1 to 0 in Cu_2O, and from +1 to +2 in $CuSO_4(aq)$. Cu is reduced to form Cu and oxidised to form Cu^{2+} in $CuSO_4$. This exemplifies how considered structuring of candidate responses can enhance their clarity. The clear labelling of C-F in the response, along with numbering which corresponds to the reactions in the question stem, make the candidate's line of reasoning easy to follow. The underlining and annotations in the question stem show good practice in picking out and interpreting key information.		Cu	H	N	O	mass	26.29	2.48	11.59	59.63	rfm	63.5	1	14	16	mol	0.414	2.48	0.828	3.73
	Cu	H	N	O																					
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			Total	8																					

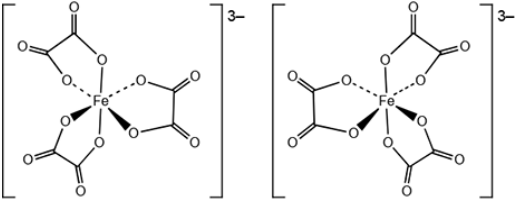
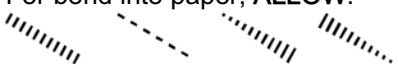
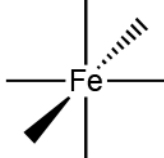
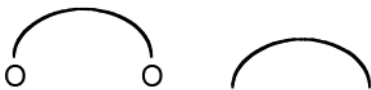
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
30		i	Equation $[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 4\text{Cl}^- \rightleftharpoons [\text{CoCl}_4]^{2-} + 6\text{H}_2\text{O}$ OR $[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 4\text{HCl} \rightleftharpoons [\text{CoCl}_4]^{2-} + 6\text{H}_2\text{O} + 4\text{H}^+ \checkmark$	1	ALLOW reverse equation: $[\text{CoCl}_4]^{2-} + 6\text{H}_2\text{O} \rightleftharpoons [\text{Co}(\text{H}_2\text{O})_6]^{2+} + 4\text{Cl}^-$ but take care for subsequent explanations IGNORE state symbols (even if wrong) For $[\text{CoCl}_4]^{2-}$, ALLOW CoCl_4^{2-}, $(\text{CoCl}_4)^{2-}$ For other representations, contact TL <u>Examiner's Comments</u> In this part, candidates needed to apply their knowledge and understanding of ligand substitution and equilibrium to a novel situation. The best equations used Cl^- ions to form CoCl_4^{2-}. Some candidates used HCl instead and then H^+ was often omitted in the equation. As with 2b, candidates are recommended to check that their completed equations are balanced.

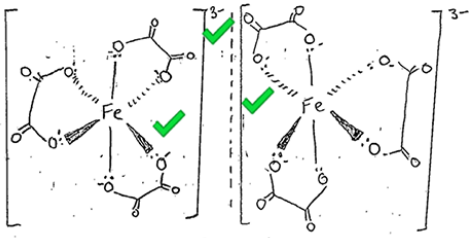
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	Equilibrium shift - equilibrium (shifts) to right at high temperature/100°C - OR equilibrium shifts to left at low temperature/0°C ✓ CARE: Direction of shift depends on direction of equilibrium equation from 2c(i). Either look back or see the equation copied at bottom of 2c(ii) marking zone. Enthalpy change - Endothermic ✓	2	Mark independently ALLOW suitable alternatives for 'to right' e.g. towards products OR in forward direction OR 'favours the right' ORA for 'to left' Temperature required but ALLOW 'in ice for low temperature' OR 'in boiling/hot water' for high temperature IGNORE shift to blue side or pink side <u>Examiner's Comments</u> Candidates were expected to determine the type of energy change by linking their equilibrium equation in 2b(i) with the colour changes at different temperatures. Most candidates correctly concluded that the formation of a blue colour is endothermic. Many candidates did not explain this in terms of a shift in equilibrium position, considering bond breaking and bond making instead.
			Total	3	

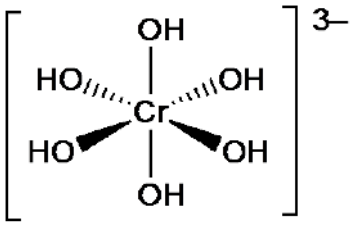
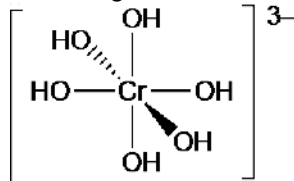
Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
31	Overall 3– charge shown (outside brackets) for at least ONE isomer ✓ 3– must apply to the overall charge of structures  1 mark for each isomer ✓✓ • Bonds must go to O ligand atoms on EACH structure • ALLOW unambiguous structures; ethanedioate ions can include C atoms For other structures that might be creditworthy, contact TL	3	ALLOW –3 for 3– IGNORE charges or dipoles on atoms within diagrams (even if wrong) Square brackets NOT required 3D Must contain 2 ‘out wedges’, 2 ‘in wedges’ and 2 lines in plane of paper OR 4 lines, 1 ‘out wedge’ and 1 ‘in wedge’: For bond into paper, ALLOW:  ALLOW following geometry throughout:  NOT ALLOW structures showing a simplified loop for ethanedioate ligands e.g.  Examiner's Comments Most candidates were able to draw clear octahedral 3D shapes of the optical isomers, with good use made of wedges. The best candidates showed an overall 3– charge on each isomer but lower ability candidates did not always cancel down the charges in the Fe³⁺ and (COO[–])₂ ions, showing a 3+ charge instead of the overall charge of 3–. (See Exemplar 5)

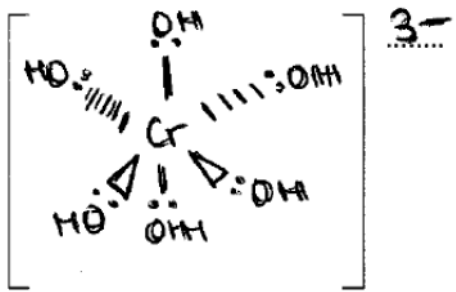
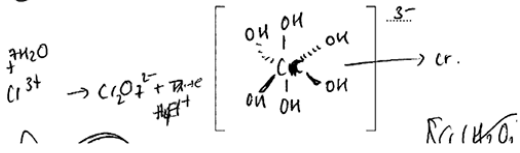
Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					Exemplar 5 
			Total	3	
32			C	1 (AO 1.1)	Examiner's Comments Only the highest attaining candidates chose the correct answer of C. Many candidates thought all 3 statements were correct (giving option A as their answer), not realising that statement 1 referred to atoms not ions
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
33		i	$[\text{Cr}(\text{NH}_3)_6]^{3+}(\text{aq}) \checkmark$	1 (AO 1.1)	IGNORE state symbols <u>Examiner's Comments</u> Most candidates knew the correct formula. There was some confusion with ammoniacal copper ions and $[\text{Cr}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ was a frequently seen incorrect answer.
		ii	$\text{CrCl}_3(\text{aq}) + 3\text{NaOH}(\text{aq}) \rightarrow \text{Cr}(\text{OH})_3(\text{s}) + 3\text{NaCl}(\text{aq})$ or $\text{Cr}^{3+}(\text{aq}) + 3\text{OH}^{-}(\text{aq}) \rightarrow \text{Cr}(\text{OH})_3(\text{s}) \checkmark$ state symbols required	1 (AO 2.8)	IGNORE square brackets around precipitate formulae ALLOW $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}(\text{aq}) + 3\text{OH}^{-}(\text{aq}) \rightarrow \text{Cr}(\text{OH})_3(\text{s}) + 3\text{H}_2\text{O}(\text{l})$ ALLOW 'hybrid' equations, Eg $\text{Cr}^{3+}(\text{aq}) + 3\text{NaOH}(\text{aq}) \rightarrow \text{Cr}(\text{OH})_3(\text{s}) + 3\text{Na}^{+}(\text{aq})$ $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}(\text{aq}) + 3\text{OH}^{-}(\text{aq}) \rightarrow \text{Cr}(\text{OH})_3(\text{s}) + 6\text{H}_2\text{O}(\text{l})$ $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}(\text{aq}) + 3\text{NaOH}(\text{aq}) \rightarrow \text{Cr}(\text{OH})_3(\text{s}) + 6\text{H}_2\text{O}(\text{l}) + 3\text{Na}^{+}(\text{aq})$ <u>Examiner's Comments</u> The most common error for this question was to omit the state symbols, sometimes on only one species. Both a correct equation and the correct state symbols were required for the mark.
		iii	 3-D diagram with all bonds through O in OH $\checkmark$ 3- charge $\checkmark$	2 (AO 1.1) (AO 2.3)	Must contain 2 'out wedges', 2 'in wedges' and 2 lines in plane of paper OR 4 lines, 1 'out wedge' and 1 'in wedge':  ALLOW dotted line OR unfilled wedge as alternatives for dotted wedge IGNORE charges inside brackets <u>Examiner's Comments</u> The drawing of simple 3-D diagrams of

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					relevant shapes is a skill that is assessed in A Level chemistry. Common errors are listed in the exemplars. Exemplar 6  Some candidates drew in pencil then overwrote in ink. Candidates need to remember that the scanned image does not differentiate between pencil and ink, so it is not necessary for them to do this. Exemplar 7  Candidates should avoid incorrect connectivity between the ligand and the central metal ion. Candidates should be taught which atom within the ligand supplies the lone pair to form the coordinate bond. In this case oxygen has lone pairs, not hydrogen as suggested by the candidate in the bonding involving the bottom left hand ligand.
		iv	CrO_4^{2-} ✓	1 (AO 3.1)	IGNORE compounds e.g. Na_2CrO_4 <u>Examiner's Comments</u> Very few candidates correctly identified the CrO_4^{2-} ion here. Candidates should be aware that oxidation of $\text{Cr}(\text{OH})_3$ produces CrO_4^{2-} (which can then be acidified to produce $\text{Cr}_2\text{O}_7^{2-}$).

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		v	orange ✓	1 (AO 1.1)	<u>Examiner's Comments</u> Invariably, the answer given by candidates here was either orange or green, indicating some knowledge of the colours of chromium ions. Those who stated orange received credit
			Total	6	
34			A	1 (AO 1.1)	
			Total	1	
35			C	1 (AO b 1.1)	
			Total	1	
36			B	1 (AO 2.1)	<u>Examiner's Comments</u> This was a challenging question, with only the most able candidates giving the correct response of B (one trans isomer and two optical cis isomers). Many candidates drew out the shapes of the isomers but some missed the two optical cis isomers (giving option A) while others thought there were two cis and two trans optical isomers, giving option C.
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
37		i	(0.00200 mol dm ⁻³ solution gives) a large titre which leads to a small (percentage) error / uncertainty ✓	1 (AO 3.4)	ALLOW (0.0200 mol dm⁻³ solution gives) a small titre which leads to a large (percentage) error / uncertainty Assume 'it' means dilute solution ALLOW 13.50 cm³ gives a lower percentage error than 1.35 cm³ <u>Examiner's Comments</u> Only a very small minority of candidates appreciated that a larger titre reduces percentage error in titre values. Most erroneously described a reading of 1.35 cm³ as being less accurate than a reading of 13.5(0) cm³. The accuracy of these is equal in the same scaled apparatus.
		ii	FIRST CHECK THE ANSWER ON ANSWER LINE If answer = 301 mg award 5 marks $n(\text{MnO}_4^-) = \frac{13.50}{1000} \times 0.00200 = 2.7(0) \times 10^{-5}$ (mol) ✓ $n(\text{Fe}^{2+}) \text{ (in } 25.0 \text{ cm}^3) = 2.7(0) \times 10^{-5} \times 5 = 1.35 \times 10^{-4} \text{ (mol) } \checkmark$ $n(\text{Fe}^{2+}) \text{ (in } 250 \text{ cm}^3) = 1.35 \times 10^{-4} \times 10 = 1.35 \times 10^{-3} \checkmark$ Mass C₁₂H₂₂FeO₁₄ in 2 tablets = $1.35 \times 10^{-3} \times 445.8 = 0.6018 \text{ (g) } \checkmark$ Mass C₁₂H₂₂FeO₁₄ in 1 tablet = 301 (mg) AND to 3 SF ✓	5 (AO 2.8 ×5)	ALLOW ECF throughout ALLOW working to 3SF minimum throughout Common errors 602 (mg) (not dividing by 2) = 4 marks 37.7 (using 55.8 instead of 445.8) = 4 marks Last mark involves dividing by two and converting g to mg. These steps may be seen earlier <u>Examiner's Comments</u> Many candidates coped well with this multi-step calculation. The common errors were: - determining the mass of C₁₂H₂₂FeO₁₄ in two tablets instead of just one tablet as required in the question - determining the mass of Fe in a tablet instead of the mass of C₁₂H₂₂FeO₁₄ - failing to convert from grams to milligrams

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	A: Mass Fe = $\frac{180 \times 55.8}{151.8} = 66 \text{ mg}$ B: Mass Fe = $\frac{210 \times 55.8}{169.8} = 69 \text{ mg}$ Iron supplement: B provides more Fe per tablet ✓	1 (AO 3.1 ×1)	ALLOW correct working if iron supplement is not named ALLOW iron(II) fumarate or $\text{C}_4\text{H}_2\text{FeO}_4$
			Total	7	
38			<i>Coordinate bond mark</i> O₂ (coordinately or datively) bonds with Fe²⁺/Fe(II)/Fe/Iron ✓ <i>Ligand substitution mark</i> (When required) O₂ is replaced by H₂O OR CO₂ OR O₂ is replaced by CO OR H₂O OR CO₂ is replaced by O₂ ✓ <i>Ligand strength mark</i> CO forms strong(er) bonds (than O₂) ✓	3 (AO 1.1 ×2) (AO 2.1 ×1)	ALLOW names or symbols of ligands ALLOW H₂O/CO/CO₂ (coordinately or datively) bonds with Fe²⁺/Fe(II)/Fe/Iron ALLOW oxygen donates electron pair to OR binds with Fe²⁺/Fe(II)/Fe/Iron DO NOT ALLOW Fe³⁺ ALLOW other words for replaced ALLOW K_{stab} for CO (much) higher (than for O₂) ALLOW CO bonds irreversibly OR CO is a strong(er) ligand IGNORE affinity Examiner's Comments The key chemistry that candidates needed to discuss in their response was as follows: • O₂ molecules forming coordinate bonds with and Fe²⁺ ions in haemoglobin. • O₂ molecules being replaced by another ligand (e.g. H₂O or CO) • CO ligands forming very strong coordinate bonds The mark scheme allowed 'oxygen binding' but candidates did need to specify what the oxygen was binding to. Loose terminology, such as CO having a 'greater affinity' should be avoided.
			Total	3	

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
39	<i>Refer to marking instructions on page 5 of mark scheme for guidance on marking this question.</i> Level 3 (5-6 marks) Comprehensive explanation of the terms, ligand and coordination number and ligand substitution AND 3D diagrams of suitable examples of 6 AND 4 coordinate complex ions with different shapes AND Ligand substitution illustrated with a balanced equation <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3-4 marks) Explanation of the terms, ligand and coordination number and ligand substitution with some errors or omissions AND: Diagrams of suitable examples of 6 AND 4 coordinate complex ions with different shapes OR A 3D wedged diagram of a suitable example of 6 OR 4 coordination OR A diagram of a suitable example of 6 OR 4 coordination AND ligand substitution illustrated with an equation OR Ligand substitution illustrated with a balanced equation <i>There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence</i> Level 1 (1-2 marks) Explanation of some terms: ligand, coordination number and ligand substitution with some errors or omissions. AND	6 (AO 1.1×4) (AO 2.1×2)	Indicative scientific points may include: <u>Terms</u> Ligand: Donates a lone pair to metal ion Forms dative covalent (coordinate) bond with metal ion Coordination number: Number of coordinate bonds to metal ion. Could be implicit in annotated diagrams NOTE: For monodentate ligands, 'number of ligands' is the same as the number of coordination number Ligand substitution: One ligand replacing another <u>Suitable examples of complex ions with different shapes</u> Coordination no 6 Octahedral e.g. $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$, $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ Coordination no 4 Tetrahedral e.g. CuCl_4^{2-}, CoCl_4^{2-} OR Square planar Pt complexes, e.g. $\text{Pt}(\text{NH}_3)_2\text{Cl}_2$ <u>Diagrams and equations</u> Diagrams of complex ions (may be 3D) Equation for ligand substitution e.g. $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 4\text{Cl}^- \rightarrow \text{CuCl}_4^{2-} + 6\text{H}_2\text{O}$ $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 4\text{NH}_3 \rightarrow [\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+} + 4\text{H}_2\text{O}$ NOTE: A clear and logically structured response would link shapes with some of: coordination number, names of shapes, connectivity, involvement of lone pairs, bond angles, etc. (not inclusive) ALLOW minor slips NOTE: Levels and the mark within a level is a 'best-fit', not perfection

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			A suitable example of a complex ion OR Ligand substitution illustrated with an equation with some errors <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks No response or no response worthy of credit.		<u>Examiner's Comments</u> This question was assessed by level of response (LoR). The question required candidates to demonstrate their knowledge and understand of some important terms used in transition metal chemistry. Level 3 candidates showed complete definitions of ligand, coordination number and ligand substitution, supported by suitable equations with clear diagrams of complex ions. The responses were concise with 3D diagrams of 6- and 4-coordinate complex ions displayed with wedges, correct connectivity to ligand atoms and showing the role of lone pairs in the formation of the coordinate bonds. 4-coordination was shown as either or both of tetrahedral (usually CuCl_4^{2-}) or square planar (e.g. platin). Ligand substitution was accompanied by a correct balanced equation, most commonly between $[\text{Cu}(\text{H}_2\text{O}_6)]^{2+}$ and NH_3. Level 2 candidates usually gave definitions of ligand, coordination number and ligand substitution. There was usually a balanced equation for ligand substitution and one correct 3D diagram. A second diagram often had an unsuitable shape for the complex ion chosen (often CuCl_4^{2-} shown as square planar). Level 1 candidates did produce definitions, but these were often incomplete. There was usually an attempt to show a 3D diagram or equation, but these often contained unsuitable examples. This question rewarded the candidates who had learnt their chemistry and the levels enabled the amount of knowledge and understanding to be assessed. The question discriminated well.
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
40	a	i	A: $\text{Fe}(\text{OH})_3(\text{s})$ ✓ B: $\text{Ag}_2\text{S}(\text{s})$ ✓✓	2 AO3.1x2	ALLOW $\text{Fe}(\text{OH})_3(\text{H}_2\text{O})_3$ IGNORE state symbols <u>Examiner's Comments</u> Most candidates were given 1 or 2 marks for this part. The black precipitate B (Ag_2S) was identified correctly more often than the orange precipitate A, which was often shown as $\text{Fe}(\text{OH})_2$ instead of $\text{Fe}(\text{OH})_3$ or $\text{Fe}(\text{OH})_3(\text{H}_2\text{O})_3$. Significantly, identification of B required interpretation of new information whereas A required knowledge of transition element chemistry.
		ii	Student is incorrect AND No oxidation numbers change OR example, e.g, Fe stays as +2 ✓	1 AO3.2	ALLOW no electron transfer <u>Examiner's Comments</u> Just over half the candidates identified that the student was incorrect, and that the reaction is not redox. Candidates were expected to provide some evidence to support their statement, in terms of no oxidation number changes. Some candidates claimed that the reaction was not redox because only sulfur changed oxidation number, suggesting a misunderstanding of redox.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iii	$2[\text{Fe}(\text{H}_2\text{O})]^{2+} + \text{Cl}_2 \rightarrow 2[\text{Fe}(\text{H}_2\text{O})_6]^{3+} + 2\text{Cl}^-$ ✓	1 AO3.1	ALLOW multiples e.g. $[\text{Fe}(\text{H}_2\text{O})_6]^{2+} + \frac{1}{2}\text{Cl}_2 \rightarrow [\text{Fe}(\text{H}_2\text{O})_6]^{3+} + \text{Cl}^-$ ALLOW $2[\text{Fe}(\text{H}_2\text{O})_6]^{2+} + \text{Cl}_2 \rightarrow 2[\text{Fe}(\text{H}_2\text{O})_5\text{OH}]^{2+} + 2\text{HCl}$ OR $2[\text{Fe}(\text{H}_2\text{O})_6]^{2+} + \text{Cl}_2 \rightarrow 2[\text{Fe}(\text{H}_2\text{O})_5\text{Cl}]^{2+} + 2\text{H}_2\text{O}$ NOTE: equation MUST be balanced by charge and oxidation number IGNORE state symbols <u>Examiner's Comments</u> Candidates found this equation extremely difficult with only a small number of candidates writing a correct equation. The problem lies with balancing the oxidation numbers and charges. Many wrote an equation with a 1:1 ratio or 1:2 ratio for $[\text{Fe}(\text{H}_2\text{O})_6]^{2+} : \text{Cl}_2$. An equation balanced in oxidation number and charge required a 2:1 ratio. When writing equations for redox reactions, candidates are recommended to check that oxidation changes and charges are balanced as well as atoms.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		iv	$5\text{H}_2\text{S} + 2\text{MnO}_4^- + 6\text{H}^+ \rightarrow 2\text{Mn}^{2+} + 5\text{S} + 8\text{H}_2\text{O}$ ✓✓ 1st mark ALL Correct species (SIX) OR Equation containing Mn and S species correctly balanced i.e. $5\text{H}_2\text{S} + 2\text{MnO}_4^- \dots\dots \rightarrow 2\text{Mn}^{2+} + 5\text{S} \dots\dots$ 2nd mark Complete correct balanced equation	2 AO3.1×2	ALLOW multiples, e.g. $2\frac{1}{2}\text{H}_2\text{S} + \text{MnO}_4^- + 3\text{H}^+ \rightarrow \text{Mn}^{2+} + 2\frac{1}{2}\text{S} + 4\text{H}_2\text{O}$ ALLOW equation with S^{2-}, e.g. $5\text{S}^{2-} + 2\text{MnO}_4^- + 16\text{H}^+ \rightarrow 2\text{Mn}^{2+} + 5\text{S} + 8\text{H}_2\text{O}$ IGNORE extra electrons for 1st mark <u>Examiner's Comments</u> Candidates needed to interpret the information in the flowchart and to use this as the basis for their redox equation. The clue that a yellow solid is a product proved to be very difficult to interpret as being sulfur. The equation then required H_2O to be added as the other product. Candidates found this equation difficult and relatively few correct equations were seen. As with (iii), many equations were not balanced by oxidation number or charge. Some candidates omitted this part entirely.
	b		<i>Please refer to the marking instructions on page 4 of this mark scheme for guidance on how to mark this question.</i> Level 3 (5–6 marks) Reaches a comprehensive conclusion to determine the correct formulae of almost all of C, D, E, F, G AND $9\text{H}_2\text{O}$ <i>There is a well-developed line of reasoning which is clear and logically structured.</i> <i>The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Reaches a sound conclusion to determine the correct formulae of at least half of C, D, E, F, G AND $9\text{H}_2\text{O}$. <i>There is a line of reasoning presented with some structure.</i> <i>The information presented is relevant and</i>	6 AO1.2×2 AO3.1×2 AO3.2×2	Indicative scientific points may include: Formula of C, D, E, F and G • C: $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ OR $\text{FeN}_3\text{O}_9 \cdot 9\text{H}_2\text{O}$ • D: FeN_3O_9 OR $\text{Fe}(\text{NO}_3)_3$ • E: Fe_2O_3 • F: NO_2 • G: O_2 • $9\text{H}_2\text{O}$ Examples of evidence $n(\text{H}_2\text{O}) = \frac{0.486}{18.0} = 0.027 \text{ (mol)}$ $0.027 : 0.003 = 1 : 9 \rightarrow 9\text{H}_2\text{O}$ $n(\text{F}) = \frac{270 - 54}{24000} = \frac{216}{24000} = 0.009(00) \text{ (mol)}$ $M(\text{E}) = 55.8 \times 2 + 16.0 \times 3 = 159.6$

Mark Scheme

Question	Answer/Indicative content	Marks	Guidance
	<i>supported by some evidence.</i> Level 1 (1–2 marks) Reaches a simple conclusion to determine the correct formulae of some of C, D, E, F, G AND 9H₂O. <i>There is an attempt at a logical structure with a line of reasoning.</i> <i>The information is in the most part relevant.</i> 0 marks No response or no response worthy of credit.		$M(F) = \frac{0.414}{0.009(00)} = 46 \text{ (g mol}^{-1}\text{)}$ G: oxygen linked to relighting glowing split NOTE: Equations could include evidence e.g. $\text{Fe(NO}_3)_3 \cdot 9\text{H}_2\text{O} \rightarrow \text{Fe(NO}_3)_3 + 9\text{H}_2\text{O}$ $\text{FeN}_3\text{O}_9 \cdot 9\text{H}_2\text{O} \rightarrow \text{FeN}_3\text{O}_9 + 9\text{H}_2\text{O}$ $2\text{Fe(NO}_3)_3 \rightarrow \text{Fe}_2\text{O}_3 + 6\text{NO}_2 + 1\frac{1}{2}\text{O}_2$ <u>Examiner's Comments</u> This question presented a practical scenario in which candidates were asked to identify 5 unknown chemicals. There are many routes that lead to correct identifications of the unknowns. Most candidates identified G as oxygen and made some headway towards identifying C and D by determining that 9 waters of crystallisation were present in C. The formulae of C and D sometimes followed but many candidates found it difficult to link 9H₂O to their formulae. The best responses showed the nitrate ion separately in the formula, e.g. Fe(NO₃)₃, but many showed the empirical formula instead, e.g. FeN₃O₉. Gas G (NO₂) proved to be the most difficult unknown to identify as it required two pieces of data for its determination. There were some very competent attempts at writing equations, with the decomposition of compound D in Stage 2 to form E, F and G being the most difficult. Exemplar 6 is a Level 3 response. The candidate has first identified C and D, having first determined the 1:9 molar ratio of C: H₂O. The candidate then writes the correct equation for Stage 1, using NO₃ for the nitrate ion. The candidate then identifies E, F and G using a methodical approach with clear working throughout. Finally, the candidate writes the correct

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			equation for the reaction in Stage 2. This is an excellent Level 3 response, given 6/6 marks. Exemplar 6 stage 1 $n = \frac{0.486}{18} = 0.027 \text{ mol}$ $0.00300 : 0.027$ $1 : 9$ empirical formula of nitrogen compound: FeN_3O_9 $D \Rightarrow \text{Fe}(\text{NO}_3)_3$ $C \Rightarrow \text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O} \rightarrow \text{Fe}(\text{NO}_3)_3 + 9\text{H}_2\text{O}$ stage 2 $\text{Fe}(\text{NO}_3)_3 \rightarrow \text{Fe}_2\text{O}_3(s) + F + G$ 0.003 Fe_2O_3 $\left. \begin{array}{l} \xrightarrow{48} \\ \xrightarrow{11.6} \end{array} \right\} 159.6$ $F = \text{Fe}_2\text{O}_3$ Additional answer space if required. stage 3 $G = 54 = 2.25 \times 10^{-3}$ 24000 $G = \text{O}_2(g)$ $\Rightarrow$ because it releases a glowing splint. $270 - 54 = 216$ $n = \frac{216}{24000} = 9 \times 10^{-3}$ $M_r = \frac{m}{n} = \frac{0.414}{9 \times 10^{-3}} = 46$ NO_2 $\left. \begin{array}{l} \xrightarrow{32} \\ \xrightarrow{14} \end{array} \right\} 46$ $F = \text{NO}_2$ stage 2 equation $2\text{Fe}(\text{NO}_3)_3 \rightarrow \text{Fe}_2\text{O}_3 + 6\text{NO}_2 + \frac{1}{2}\text{O}_2$
	Total	12	

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41		i	$(1s^2)2s^22p^63s^23p^63d^2$ ✓	1 (AO 1.1)	ALLOW upper case D, etc. and subscripts, e.g. $3D_2$ If included, ALLOW $4s^0$ Examiner's Comments Many candidates did not realise that when transition metal ions are formed, the first electrons removed from atoms are the 4s electrons and so wrote $2s^2 2p^6 3s^2 3p^6 3d^1 4s^2$.
		ii	<i>Explanation of colours</i> VO^{2+} goes to V^{3+} (green) AND then V^{3+} goes to V^{2+} (violet) ✓ <i>Explanation using $E^\ominus$ values</i> $(E^\ominus$ of) system 4 (VO^{2+}/V^{3+}) is more positive / less negative than system 2 (Fe^{2+}/Fe) OR $(E^\ominus$ of) system 3 (V^{3+}/V^{2+}) is more positive / less negative than system 2 (Fe^{2+}/Fe) ✓ <i>Equilibrium shift related to $E^\ominus$ values</i> More positive/less negative system 4 (VO^{2+}/V^{3+}) shifts right AND More positive/less negative system 3 (V^{3+}/V^{2+}) shifts right	3 (AO 3.2 ×2) (AO 3.2×1)	IGNORE 'lower/higher' ALLOW reverse argument System 2 more negative than system 4 etc $E = (+)0.78$ V for system 4 + system 2 reaction OR $E = (+)0.18$ V for system 3 + system 2 reaction For shifts right' ALLOW (VO^{2+}) is reduced OR gains electrons (maybe seen as an equation) AND 'For shifts right' ALLOW (V^{3+}) is reduced OR gains electrons (maybe seen as an equation) IGNORE Fe oxidised Examiner's Comments Most candidates did not state that the direction of reaction of redox equilibria is dependent on the relative negativity/positivity of the standard electrode potentials. Higher ability candidates described two reductions of the relevant vanadium ions to end up with V^{2+} ions.

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		iii	$\text{Fe} + 4\text{H}^+ + 2\text{VO}^{2+} \rightarrow \text{Fe}^{2+} + 2\text{H}_2\text{O} + 2\text{V}^{3+}$	1 (AO 2.8)	IGNORE state symbols ALLOW multiples ALLOW ' $\rightleftharpoons$ '
			Total	5	

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42	<i>Refer to marking instructions on page 5 of mark scheme for guidance on marking this question.</i> Level 3 (5–6 marks) All three tests are covered in detail, with at least six of B to H identified correctly and equations mostly correct. <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) All three tests are covered with at least four of B to H identified correctly. Some attempt at writing equations, but with several omissions or incorrect formulae. <i>There is a line of reasoning presented with some structure. The information presented is relevant and supported by some evidence.</i> Level 1 (1–2 marks) Only two tests covered with at least two of B to H identified correctly, and little attempt at writing equations. <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks <i>No response or no response worthy of credit.</i>	6 (AO 3.3×3) (AO 3.4×3)	Indicative scientific points may include: Identification of unknowns Can be identified within labelled equation. B is FeSO_4 OR Iron(II) sulfate • Test 1: Fe^{2+} present • Test 2: SO_4^{2-} present D is $\text{Fe}(\text{OH})_2$ OR $[\text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2]$ OR iron(II) hydroxide G is BaSO_4 OR barium sulfate C is CrCl_3 OR chromium(III) chloride • Test 1: Cr^{3+} present • Test 3: Cl^- present E is $\text{Cr}(\text{OH})_3$ OR $[\text{Cr}(\text{H}_2\text{O})_3(\text{OH})_3]$ OR chromium(III) hydroxide F is $[\text{Cr}(\text{NH}_3)_6]^{3+}$ H is silver chloride OR AgCl Equations D: $[\text{Fe}(\text{H}_2\text{O})_6]^{2+} + 2\text{OH}^- \rightarrow \text{Fe}(\text{OH})_2 + 6\text{H}_2\text{O}$ OR $\text{Fe}^{2+} + 2\text{OH}^- \rightarrow \text{Fe}(\text{OH})_2$ OR $[\text{Fe}(\text{H}_2\text{O})_6]^{2+} + 2\text{OH}^- \rightarrow [\text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2] + 2\text{H}_2\text{O}$ OR $[\text{Fe}(\text{H}_2\text{O})_6]^{2+} + 2\text{NH}_3 \rightarrow [\text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2] + 2\text{NH}_4^+$ OR $[\text{Fe}(\text{H}_2\text{O})_6]^{2+} + 2\text{NH}_3 \rightarrow \text{Fe}(\text{OH})_2 + 4\text{H}_2\text{O} + 2\text{NH}_4^+$ E: $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 3\text{OH}^- \rightarrow \text{Cr}(\text{OH})_3 + 6\text{H}_2\text{O}$ OR $\text{Cr}^{3+} + 3\text{OH}^- \rightarrow \text{Cr}(\text{OH})_3$ OR $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 3\text{OH}^- \rightarrow [\text{Cr}(\text{H}_2\text{O})_3(\text{OH})_3] + 3\text{H}_2\text{O}$ OR $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 3\text{NH}_3 \rightarrow [\text{Cr}(\text{H}_2\text{O})_3(\text{OH})_3] + 3\text{NH}_4^+$ OR $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 3\text{NH}_3 \rightarrow \text{Cr}(\text{OH})_3 + 3\text{H}_2\text{O} + 3\text{NH}_4^+$ F: $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 6\text{NH}_3 \rightarrow [\text{Cr}(\text{NH}_3)_6]^{3+} + 6\text{H}_2\text{O}$ OR $\text{Cr}(\text{OH})_3 + 6\text{NH}_3 \rightarrow [\text{Cr}(\text{NH}_3)_6]^{3+} + 3\text{OH}^-$ OR $[\text{Cr}(\text{H}_2\text{O})_3(\text{OH})_3] + 6\text{NH}_3 \rightarrow [\text{Cr}(\text{NH}_3)_6]^{3+} + 3\text{H}_2\text{O} + 3\text{OH}^-$

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					G: $\text{Ba}^{2+} + \text{SO}_4^{2-} \rightarrow \text{BaSO}_4$ H: $\text{Ag}^+ + \text{Cl}^- \rightarrow \text{AgCl}$
			Total	6	