Transition Elements

1. * **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 excess NH_3(aq) added	green precipitate **D** no further change	grey-green precipitate **E** purple solution **F**
2	HNO_3(aq) followed by $Ba(NO_3)_2$(aq)	no change white precipitate **G**	no change no change
3	HNO_3(aq) followed by $AgNO_3$(aq)	no change no change	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]**

2. 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.

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____ **[6]**

3. Iron(II) gluconate, $C_{12}H_{22}FeO_{14}$, 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 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 mol dm^{-3} potassium manganate(VII) solution for this titration, rather than the more usual concentration of 0.0200 mol dm^{-3} used in manganate(VII) titrations.

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____ **[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, $C_4H_2FeO_4$	210

Table 18.3

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

iron supplement: .... **[1]**

4. Red blood cells contain haemoglobin.

Explain using ligand substitutions:

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

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____ **[3]**

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

A student carries out two experiments on a solution containing $[Cr(H_2O)_6]^{3+}(aq)$.

Experiment 1
The student adds an excess of aqueous ammonia to a solution containing $[Cr(H_2O)_6]^{3+}(aq)$ until a purple solution is formed.

Experiment 2
The student carries out the following reaction sequence.

Step 1	NaOH(aq) is added slowly to a solution containing $[Cr(H_2O)_6]^{3+}(aq)$ in a boiling tube. A grey–green precipitate forms.
Step 2	An excess of NaOH(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 $Cr_2O_7^{2-}(aq)$.

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]**

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

Oxidation state of vanadium	Vanadium ion	Colour
+5	$VO_2^+(aq)$	yellow
+4	$VO^{2+}(aq)$	blue
+3	$V^{3+}(aq)$	green
+2	$V^{2+}(aq)$	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 VO^{2+}(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^e / V**
1	V^{2+}(aq) + 2e$^-$ ⇌ V(s)	–1.18
2	Fe^{2+}(aq) + 2e$^-$ ⇌ Fe(s)	–0.44
3	V^{3+}(aq) + e$^-$ ⇌ V^{2+}(aq)	–0.26
4	VO^{2+}(aq) + 2H$^+$ + e$^-$ ⇌ V^{3+}(aq) + H_2O(l)	+0.34
5	Fe^{3+}(aq) + e$^-$ ⇌ Fe^{2+}(aq)	+0.77
6	VO_{2}^{+}(aq) + 2H$^+$ + e$^-$ ⇌ VO^{2+}(aq) + H_2O(l)	+1.00

Table 18.2

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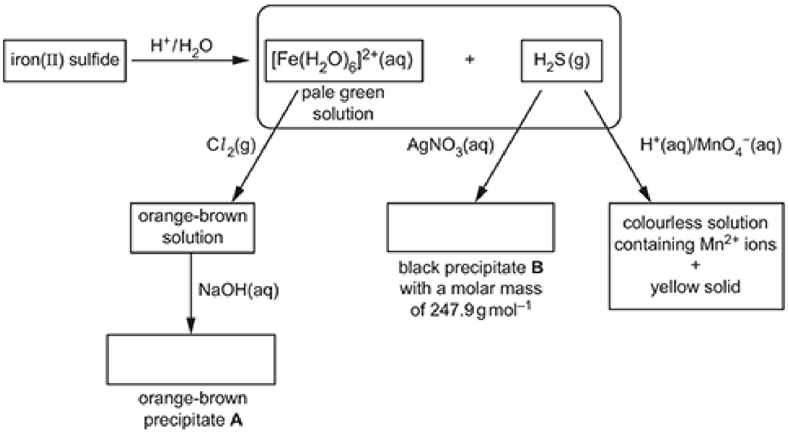
____ **[3]**

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

____ **[1]**

6(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 H^+ / H_2O is a redox reaction.

Explain, with reasons, whether the student is correct.

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____ **[1]**

iii. Write the equation for the reaction of $[Fe(H_2O)_6]^{2+}$(aq) with Cl_2(g).

____ **[1]**

iv. Construct an equation for the reaction of H_2S(g) with H^+(aq)/MnO_4^-(aq).

[2]

(b). *Compound **C** is a hydrated ionic compound with the empirical formula: $FeH_{18}N_3O_{18}$.

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.

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____ **[6]**

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

- With water ligands, cobalt(II) forms a pink octahedral complex ion, $[Co(H_2O)_6]^{2+}$.
- 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.

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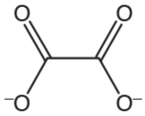
____ **[2]**

8. This question is about ethanedioic acid, $(COOH)_2$, and ethanedioate ions, $(COO^-)_2$.

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]

9(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.

$Zn^{2+}(aq) + 2e^-$	$\rightleftharpoons$	$Zn(s)$	$E^\ominus = -0.76\,V$
$Cr^{3+}(aq) + e^-$	$\rightleftharpoons$	$Cr^{2+}(aq)$	$E^\ominus = -0.42\,V$
$Ni^{2+}(aq) + 2e^-$	$\rightleftharpoons$	$Ni(s)$	$E^\ominus = -0.25\,V$
$I_2(aq) + 2e^-$	$\rightleftharpoons$	$2I^-(aq)$	$E^\ominus = +0.54\,V$
$Fe^{3+}(aq) + e^-$	$\rightleftharpoons$	$Fe^{2+}(aq)$	$E^\ominus = +0.77\,V$
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^-$	$\rightleftharpoons$	$2Cr^{3+}(aq) + 7H_2O(l)$	$E^\ominus = +1.33\,V$
$H_2O_2(aq) + 2H^+(aq) + 2e^-$	$\rightleftharpoons$	$2H_2O(l)$	$E^\ominus = +1.78\,V$

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]**

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10(a). 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%; C*l*, 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**.

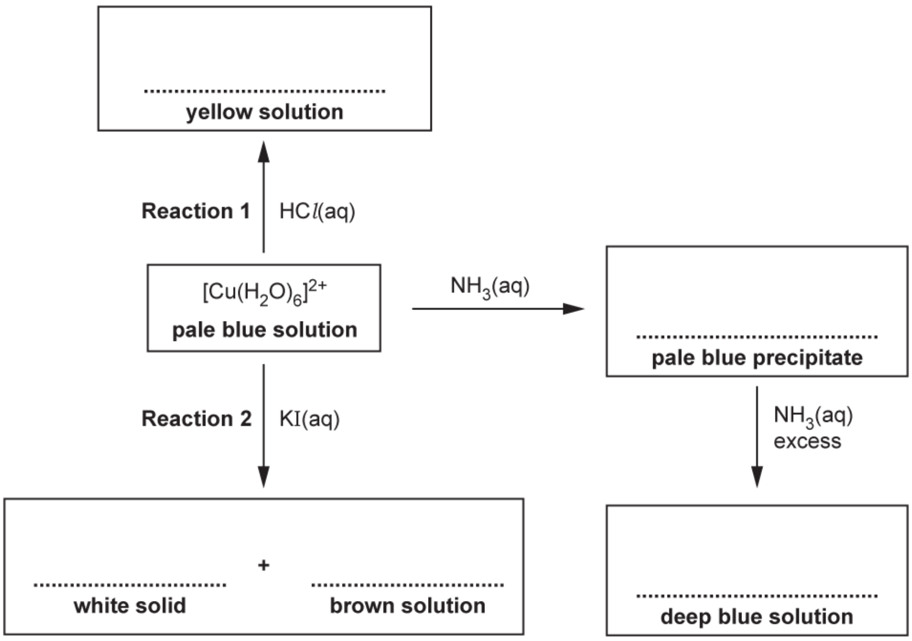
Show **all** your working.

--- **[6]**

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

The flowchart shows reactions of the complex ion $[Cu(H_2O)_6]^{2+}$.

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



[5]

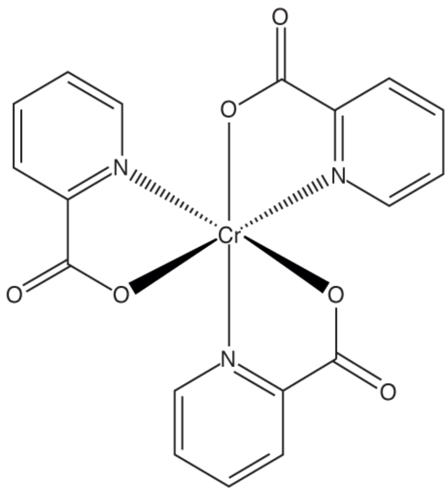
ii. Name the type of reaction for **Reaction 1** and **Reaction 2**.

Reaction 1 --

Reaction 2 --

[2]

11. 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.

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 μg = 10^{-6} g.

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

mass = ________________________________

12. 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]

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

A garden product contains hydrated ammonium iron(II) sulfate, $(NH_4)_2Fe(SO_4)_2{\bullet}xH_2O$.
$(NH_4)_2Fe(SO_4)_2{\bullet}xH_2O$ contains 27.55% by mass of water of crystallisation.

Calculate the value of *x* in the formula $(NH_4)_2Fe(SO_4)_2{\bullet}xH_2O$.

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, $(NH_4)_2Fe(SO_4)_2{\bullet}xH_2O$, which is soluble in water
- Crushed limestone (calcium carbonate)
- Sand.

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

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____ **[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 $(NH_4)_2Fe(SO_4)_2 \cdot xH_2O$
- 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]

14 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 $[Co(NH_3)_6]^{2+}$.

i. Write the equation for the formation of $[Co(NH_3)_6]^{2+}$ from complex ion **B**.

State the type of reaction.

Equation
………
……………………

Type of reaction
………
………… **[2]**

ii. Draw a 3-D diagram of the $[Co(NH_3)_6]^{2+}$ ion.

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

[2]

iii. A solution containing $[Co(NH_3)_6]^{2+}$ is reacted as outlined below.

- The solution is warmed with aqueous hydrogen peroxide, $H_2O_2(aq)$. 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%; C*l*, 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 $[Co(NH_3)_6]^{2+}$ to **C** by hydrogen peroxide in **(iii)**.

Half equations

Overall equation

[3]

15. When heated with dilute acid, $MnO_4^{2-}(aq)$ ions disproportionate into MnO_4^- and MnO_2.

i. Balance the equation for this disproportionation reaction.

...... $MnO_4^{2-}(aq)$ + ... $H^+(aq) \rightleftharpoons$ ...... $MnO_4^-(aq)$ + ... $MnO_2(s)$ + ... $H_2O(l)$

[1]

ii. Although $MnO_4^{2-}(aq)$ ions disproportionate in acidic conditions, $MnO_4^{2-}(aq)$ ions are stable under alkaline solutions.

Explain this difference in stability, in terms of equilibrium.

--- **[2]**

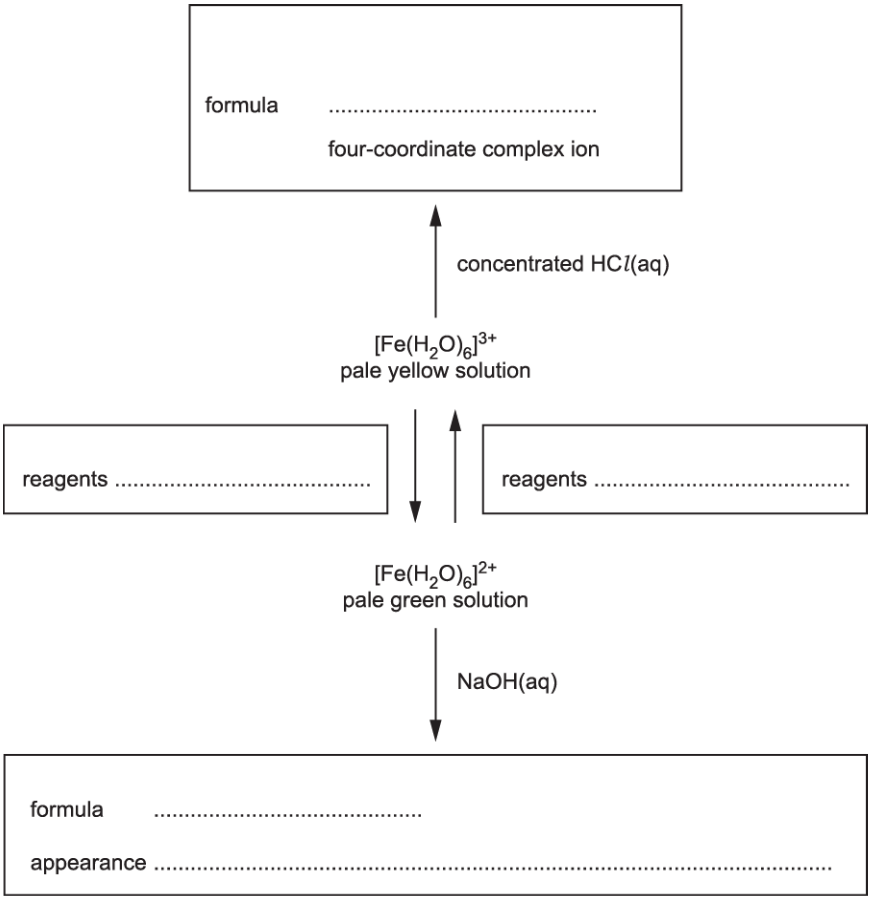
16 This question is about reactions and properties of d-block elements.
.
Iron forms many compounds and ions in the +2 and +3 oxidation states.

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.



[4]

17. 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: ....

  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:
....

18(a). Hydrated copper(II) methanoate, $Cu(HCOO)_2 \cdot xH_2O$, is a copper salt.

A student carries out the procedure below to prepare $Cu(HCOO)_2 \cdot xH_2O$ and to determine the value of *x* in its formula.

Step 1
The student prepares $Cu(HCOO)_2 \cdot xH_2O$ by reacting a copper compound with aqueous methanoic acid to form $Cu(HCOO)_2(aq)$ and allowing the solvent to evaporate.

Step 2
The student dissolves 2.226 g of $Cu(HCOO)_2 \cdot xH_2O$ 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 KI(aq).

The $Cu^{2+}(aq)$ ions react to form a precipitate of copper(I) iodide and $I_2(aq)$.
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 mol dm^{-3} $Na_2S_2O_3$ (aq).

$I_2(aq) + 2S_2O_3^{2-}(aq) \rightarrow 2I^-(aq) + S_4O_6^{2-}(aq)$

23.5 cm^3 0.0420 mol dm^{-3} $Na_2S_2O_3$ (aq) is required to reach the end point.

Complete the electron configuration of copper in

$Cu(HCOO)_2 \cdot xH_2O$: $1s^2$ ....

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 $Cu(HCOO)_2(aq)$.

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 $Cu(HCOO)_2{\bullet}xH_2O$.

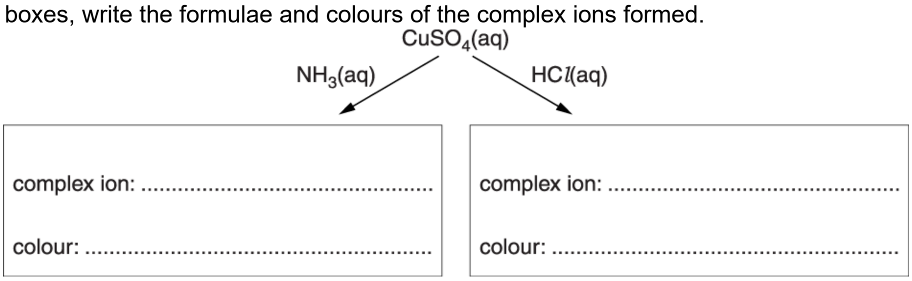
Show your working.

[5]

19(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.



[3]

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

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

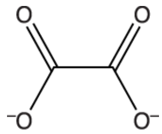


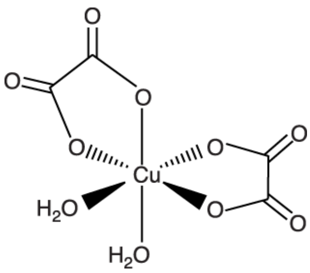
Fig. 1.1

i. What is meant by the term *bidentate ligand*?

--- **[1]**

ii. The complex ion **A** exists as three stereoisomers.

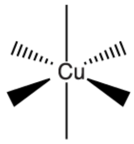
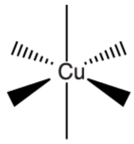
The shape of one of the stereoisomers is shown below. The charge has been omitted.



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	*cis* ☐ *trans* ☐ optical ☐	*cis* ☐ *trans* ☐ optical ☐

[3]

iii. What is the empirical formula, including the charge, of the complex ion **A**?

____ **[2]**

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

$Fe^{2+}(aq) + 2e^-$	$\rightleftharpoons$	$Fe(s)$	$E^\circ = -0.44V$
$Fe^{3+}(aq) + e^-$	$\rightleftharpoons$	$Fe^{2+}(aq)$	$E^\circ = +0.77V$
$\frac{1}{2}I_2(aq) + e^-$	$\rightleftharpoons$	$I^-(aq)$	$E^\circ = +0.54V$
$\frac{1}{2}Br_2(aq) + e^-$	$\rightleftharpoons$	$Br^-(aq)$	$E^\circ = +1.09V$
$\frac{1}{2}Cl_2(aq) + e^-$	$\rightleftharpoons$	$Cl^-(aq)$	$E^\circ = +1.36V$

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

Fe^{2+}:
$1s^2$ ____

Br^-: $1s^2$ ____

[2]

ii. Predict the products of reacting Fe(s) separately with I_2(aq), Br_2(aq) and Cl_2(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 $[Fe(H_2O)_6]^{2+}$ 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]**

21(a). An octahedral complex ion **A**, $C_9H_{30}N_6Ni^{3+}$, 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.

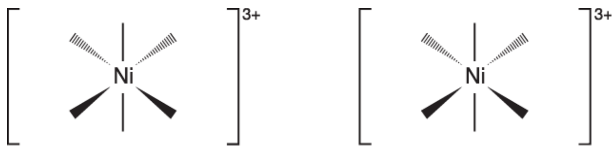
[2]

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]

(b). 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]

22(a). A student carries out an investigation to prepare and analyse a sample of barium ferrate(VI), $BaFeO_4$. 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, $FeO_4^{2-}(aq)$, 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 $BaFeO_4$ reacts as shown below, and the impurity does not react. A solution forms containing aqueous iodine, $I_2(aq)$.

$$BaFeO_4(s) + 8H^+(aq) + 3I^-(aq) \rightarrow Fe^{3+}(aq) + Ba^{2+}(aq) + 1\tfrac{1}{2}I_2(aq) + 4H_2O(l)$$

Step 4

The student determines the amount of I_2 formed by carrying out a titration with aqueous sodium thiosulfate, $Na_2S_2O_3(aq)$.

$$2S_2O_3^{2-}(aq) + I_2(aq) \rightarrow S_4O_6^{2-}(aq) + 2I^-(aq)$$

26.4 cm^3 of 0.100 mol dm^{-3} $Na_2S_2O_3(aq)$ 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 1.333×10^{-3} 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]

23(a). Elements in the d-block of the Periodic Table form ions that combine with ligands to form complex ions. Most d-block elements are also classified as transition elements.

Explain why two of the Period 4 d-block elements (Sc—Zn) are **not** also transition elements.

In your answer you should link full electron configurations to your explanations.

____

____

____

____

____

____

____

____

____ **[6]**

(b). The cobalt(III) ion, Co^{3+}, forms a complex ion **A** with two chloride ligands and two ethanediamine, $H_2NCH_2CH_2NH_2$, 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]

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

$$Hb(aq) + O_2(aq) \rightleftharpoons HbO_2(aq)$$ **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]**

24(a). A redox reaction takes place when copper metal is heated with concentrated sulfuric acid. A blue solution forms and 95.0 cm^3 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.

$Fe^{2+}(aq) + 2e^-$	⇌	$Fe(s)$	$E^\ominus = -0.44$ V
$2H^+ (aq) + 2e^-$	⇌	H2(g)	$E^\ominus = 0.00$ V
$Fe^{3+}(aq) + e^-$	⇌	$Fe^{2+}(aq)$	$E^\ominus = +0.77$ V
$O_2(g) + 4H^+(aq) + 4e^-$	⇌	$2H_2O(l)$	$E^\ominus = +1.23$ V
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^-$	⇌	$2Cr^{3+}(aq) + 7H_2O(l)$	$E^\ominus = +1.33$ V
$Cl_2(g) + 2e^-$	⇌	$2Cl^-(aq)$	$E^\ominus = +1.36$ V
$H_2O_2(aq) + 2H^+(aq) + 2e^-$	⇌	$2H_2O(l)$	$E^\ominus = +1.78$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]**

25(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 $CoN_4H_{12}Cl_3$.

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]

(c). **A** and **B** are compounds of two different transition elements.

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

The observations of **Student 1's** tests are shown below.

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**

i. Analyse the results and answer the following.

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 HNO_3(aq) first in **Test 2** and **Test 3**?

--- **[1]**

iii. **Student 2** accidentally used HC*l*(aq) instead of HNO_3(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]**

END OF QUESTION PAPER