Q1.(a) A sample of solid chromium(III) hydroxide displays amphoteric character when treated separately with dilute hydrochloric acid and with dilute aqueous sodium hydroxide.

Write an ionic equation for each of these reactions. Include the formula of each complex ion formed.
Describe the changes that you would observe in each reaction.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(5)

(b) Aqueous solutions of copper(II) sulfate and cobalt(II) sulfate undergo ligand substitution reactions when treated separately with an excess of dilute aqueous ammonia.

Write equations for these reactions. Include the formulae for any complex ions.
Describe the changes that you would observe in each reaction.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(6)
(Total 11 marks)

Q2. What is the final species produced when an excess of aqueous ammonia is added to aqueous aluminium chloride?

A $[Al(NH_3)_6]^{3+}$ ⬭

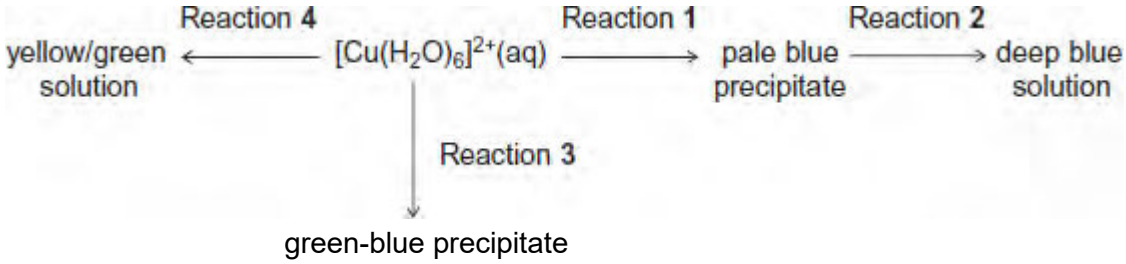
B $[Al(OH)_3(H_2O)_3]$ ⬭

C $[Al(OH)_4(H_2O)_2]^-$ ⬭

D $[Al(OH)(H_2O)_5]^{2+}$ ⬭

(Total 1 mark)

Q3. Consider the following reaction scheme that starts from aqueous $[Cu(H_2O)6]^{2+}$ ions.



For each of the reactions **1** to **4**, identify a suitable reagent, give the formula of the copper-containing species formed and write an equation for the reaction.

(a) Reaction **1**

Reagent .....

Copper-containing species .....

Equation .....

(3)

(b) Reaction **2**

Reagent .....

Copper-containing species .....

Equation .....

(3)

(c) Reaction **3**

Reagent .....

Copper-containing species .....

Equation .....

(3)

(d) Reaction **4**

Reagent .....

Copper-containing species .....

Equation .....

(3)
(Total 12 marks)

Q4. A green solution, **X**, is thought to contain $[Fe(H_2O)_6]^{2+}$ ions.

(a) The presence of these ions can be confirmed by reacting separate samples of solution **X** with aqueous ammonia and with aqueous sodium carbonate.

Write equations for each of these reactions and describe what you would observe.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(4)

(b) A 50.0 cm^3 sample of solution **X** was added to 50 cm^3 of dilute sulfuric acid and made up to 250 cm^3 of solution in a volumetric flask.

A 25.0 cm^3 sample of this solution from the volumetric flask was titrated with a 0.0205 mol dm^{-3} solution of $KMnO_4$
At the end point of the reaction, the volume of $KMnO_4$ solution added was 18.70 cm^3.

(i) State the colour change that occurs at the end point of this titration and give a reason for the colour change.

.....

.....

.....

.....

(2)

(ii) Write an equation for the reaction between iron(II) ions and manganate(VII) ions.

Use this equation and the information given to calculate the concentration of iron(II) ions in the original solution **X**.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(5)

(Total 11 marks)

Q5. Which compound gives a colourless solution when an excess of dilute aqueous ammonia is added?

A $MgCl_2$ ⬭

B AgCl ⬭

C $CuCl_2$ ⬭

D $AlCl_3$ ⬭

(Total 1 mark)

Q6. What forms when a solution of sodium carbonate is added to a solution of gallium(III) nitrate?

A A white precipitate of gallium(III) carbonate. ⬭

B A white precipitate of gallium(III) hydroxide. ⬭

C A white precipitate of gallium(III) carbonate and bubbles of carbon dioxide. ⬭

D A white precipitate of gallium(III) hydroxide and bubbles of carbon dioxide. ⬭

(Total 1 mark)

Q7.(a) A co-ordinate bond is formed when a transition metal ion reacts with a ligand.

Explain how this co-ordinate bond is formed.

.....

.....

.....

.....

.....

(2)

(b) Describe what you would observe when dilute aqueous ammonia is added dropwise, to excess, to an aqueous solution containing copper(II) ions. Write equations for the reactions that occur.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(4)

(c) When the complex ion $[Cu(NH_3)_4(H_2O)_2]^{2+}$ reacts with 1,2-diaminoethane, the ammonia molecules but not the water molecules are replaced.

Write an equation for this reaction.

.....

(1)

(d) Suggest why the enthalpy change for the reaction in part **(c)** is approximately zero.

.....

.....

.....

.....

.....

(2)

(e) Explain why the reaction in part **(c)** occurs despite having an enthalpy change that is approximately zero.

.....

.....

.....

.....

.....

(2)
(Total 11 marks)

Q1. An excess of a given reagent is added to each of the following pairs of aqueous metal ions.

For each metal ion, state the initial colour of the solution and the final observation that you would make.

In each case, write an overall equation for the formation of the final product from the initial aqueous metal ion.

(a) An excess of aqueous sodium carbonate is added to separate aqueous solutions containing $[Fe(H_2O)_6]^{2+}$ and $[Fe(H_2O)_6]^{3+}$.

.....

.....

.....

.....

.....

.....

.....

.....

.....

(5)

(b) An excess of concentrated hydrochloric acid is added to separate aqueous solutions containing $[Cu(H_2O)_6]^{2+}$ and $[Co(H_2O)_6]^{2+}$.

.....

.....

.....

.....

.....

.....

.....

(4)

(c) An excess of dilute aqueous sodium hydroxide is added to separate aqueous

solutions containing $[Fe(H_2O)_6]^{2+}$ and $[Cr(H_2O)_6]^{3+}$.

.....

.....

.....

.....

.....

.....

.....

.....

(4)

(d) An excess of dilute aqueous ammonia is added to separate aqueous solutions containing $[Al(H_2O)_6]^{3+}$ and $[Ag(H_2O)_2]^{+}$

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(4)
(Total 17 marks)

Q2. This question is about test-tube reactions of some ions in aqueous solution.

For each reaction in parts (a) to (d), state the colour of the original solution.
State what you would observe after the named reagent has been added to the solution.
In each case, write an equation for the reaction that occurs.

(a) An excess of dilute sulfuric acid is added to a solution containing CrO_4^{2-} ions.

Colour of original solution .....

Observation after an excess of reagent has been added .....

.....

Equation

.....

(3)

(b) Sodium hydroxide solution is added to a solution containing $[Fe(H_2O)_6]^{3+}$ ions.

Colour of original solution .....

Observation after reagent has been added .....

.....

Equation

.....

(3)

(c) An excess of ammonia solution is added to a solution containing $[Cu(H_2O)_6]^{2+}$ ions.

Colour of original solution .....

Observation after an excess of reagent has been added .....

.....

Equation

.....

(3)

(d) Sodium carbonate solution is added to a solution containing $[Al(H_2O)_6]^{3+}$ ions.

Colour of original solution .....

Observations after reagent has been added .....

.....

.....

.....

Equation

.....

(4)
(Total 13 marks)

Q3. Iron(II) sulfate is used to kill weeds in garden lawns. It is a by-product of the manufacture of steel.
When a lawn is treated with iron(II) sulfate, the iron(II) ions are oxidised to form iron(III) ions.

Iron(III) ions are acidic in aqueous solution as shown by the following equation.

$$[Fe(H_2O)_6]^{3+}(aq) \rightleftharpoons [Fe(H_2O)_5(OH)]^{2+}(aq) + H^+(aq)$$

In an experiment, a calibrated pH meter was used to measure the pH of an iron(III) salt in solution. At 20 °C the pH of a 0.100 mol dm^{-3} solution of iron(III) sulfate was found to be 1.62.

(a) Explain briefly why a pH meter should be calibrated before use.

.....

.....

(1)

(b) Write an expression for the equilibrium constant, K_a, for the dissociation of iron(III) ions in aqueous solution.

.....

.....

(1)

(c) Use your answer from part (b) to calculate the value of K_a for this reaction at 20 °C. Give your answer to the appropriate precision. Show your working.

.....

.....

.....

.....

.....

.....

(4)

(d) Name the substance that is most likely to oxidise the iron(II) ions when iron(II) sulfate is used as a weed killer.

.....

(1)

(e) Suggest a value for the pH of a 0.100 mol dm^{-3} solution of iron(II) sulfate.

.....

(1)

(Total 8 marks)

Q4. In its reactions with transition metal ions, ammonia can act as a Brønsted–Lowry base and as a Lewis base.

(a) Define the term *Lewis base*.

.....

.....

.....

(1)

(b) Write an equation for a reaction between aqueous copper(II) ions ($[Cu(H_2O)_6]^{2+}$) and ammonia in which ammonia acts as a Brønsted–Lowry base. State what you would observe.

.....

.....

.....

.....

(Extra space) .....

.....

(2)

(c) Write an equation for a different reaction between aqueous copper(II) ions ($[Cu(H_2O)_6]^{2+}$) and ammonia in which ammonia acts as a Lewis base but **not** as a Brønsted–Lowry base. State what you would observe.

.....

.....

.....

.....

(Extra space) .....

.....

(2)

(d) An excess of dilute ammonia solution is added to an aqueous solution containing iron(II) ions in a test tube that is then left to stand for some time.
State and explain what you would observe.

.....

.....

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

(4)

(e) Diaminoethane ($H_2NCH_2CH_2NH_2$), like ammonia, can react as a base and as a ligand.

(i) Write an equation for the reaction that occurs between an aqueous solution of aluminium chloride and an excess of aqueous diaminoethane.
Describe the appearance of the aluminium-containing reaction product.

.....

.....

.....

.....

(Extra space) .....

.....

(3)

(ii) Write an equation for the reaction that occurs between an aqueous solution of cobalt(II) sulfate and an excess of aqueous diaminoethane.
Draw a diagram to show the shape of and bonding in the complex product.
Write an equation for the reaction that would occur if the complex product of this reaction were allowed to stand in contact with oxygen gas.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(5)
(Total 17 marks)

Q1. Aqueous metal ions can be identified by test-tube reactions.

For each of the following, describe what you would observe.

Write an equation or equations for any reactions that occur.

(a) The addition of aqueous sodium carbonate to a solution containing $[Fe(H_2O)_6]^{3+}(aq)$ ions.

.....

.....

.....

.....

.....

.....

(4)

(b) The addition of aqueous sodium hydroxide, dropwise until in excess, to a solution containing $[Al(H_2O)_6]^{3+}(aq)$ ions.

.....

.....

.....

.....

.....

.....

(4)

(c) The addition of dilute aqueous ammonia, dropwise until in excess, to a solution containing $[Cu(H_2O)_6]^{2+}(aq)$ ions.

.....

.....

.....

.....

.....

.....

(4)

(d) The addition of concentrated hydrochloric acid, dropwise until in excess, to a solution containing $[Cu(H_2O)_6]^{2+}(aq)$ ions.

.....

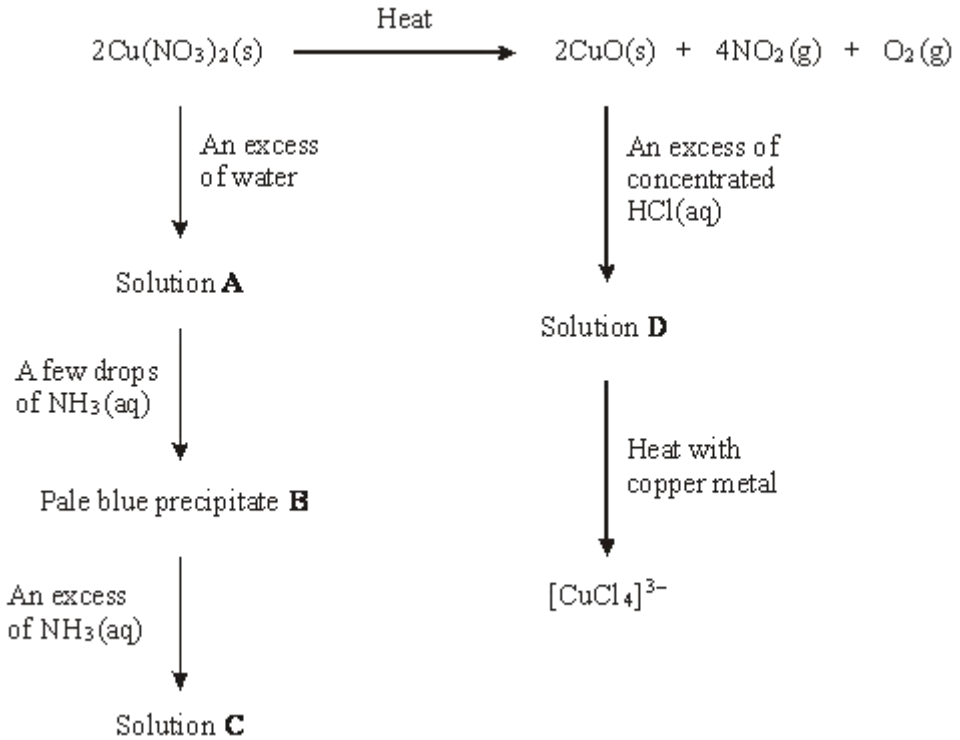
.....

.....

.....

(2)
(Total 14 marks)

Q2. Consider the reaction scheme below and answer the questions which follow.



(a) A redox reaction occurs when $Cu(NO_3)_2$ is decomposed by heat. Deduce the oxidation state of nitrogen in $Cu(NO_3)_2$ and in NO_2 and identify the product formed by oxidation in this decomposition.

Oxidation state of nitrogen in $Cu(NO_3)_2$ .....

Oxidation state of nitrogen in NO_2 .....

Oxidation product .....

.....

(3)

(b) Identify and state the shape of the copper-containing species present in solution **A**.

Copper-containing species .....

Shape .....

(2)

(c) (i) Identify the pale blue precipitate **B** and write an equation, or equations, to show how **B** is formed from the copper-containing species in solution **A**.

*Identity of precipitate **B*** .....

Equation(s) .....

.....

(ii) In what way does the NH_3 behave as a Brønsted–Lowry base?

.....

(3)

(d) (i) Identify the copper-containing species present in solution **C**. State the colour of this copper-containing species and write an equation for its formation from precipitate **B**.

Identity .....

Colour .....

Equation ….....

.....

(ii) In what way does the NH_3 behave as a Lewis base?

.....

(4)

(e) Identify the copper-containing species present in solution **D**. State the colour and shape of this copper-containing species.

Identity .....

Colour .....

Shape .....

.....

(3)

(f) The oxidation state of copper in $[CuCl_4]^{3-}$ is +1.

(i) Give the electron arrangement of a Cu^+ ion.

.....

(ii) Deduce the role of copper metal in the formation of $[CuCl_4]^{3-}$ from the copper-containing species in solution **D**.

.....

(2)
(Total 17 marks)

Q3. (a) In the Haber Process for the manufacture of ammonia, the following equilibrium is established in the presence of a heterogeneous catalyst.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

Identify the heterogeneous catalyst used in this process and state what is meant by the term *heterogeneous*.

A heterogeneous catalyst can become poisoned by impurities in the reactants. Give one substance which poisons the heterogeneous catalyst used in the Haber Process and explain how this substance poisons the catalyst.

(5)

(b) State what is observed when an excess of aqueous ammonia reacts with an aqueous iron(II) salt. Write an equation for this reaction.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total 9 marks)

Q1. (a) State what is meant by each of the following terms.

(i) *Ligand* .....

.....

(ii) *Complex ion* .....

.....

(iii) *Co-ordination number* .....

.....

(3)

(b) Using complex ions formed by Co^{2+} with ligands selected from H_2O, NH_3, Cl^-, $C_2O_4^{2-}$ and $EDTA^{4-}$, give an equation for each of the following.

(i) A ligand substitution reaction which occurs with no change in either the co-ordination number or in the charge on the complex ion.

.....

(ii) A ligand substitution reaction which occurs with both a change in the co-ordination number and in the charge on the complex ion.

.....

(iii) A ligand substitution reaction which occurs with no change in the co-ordination number but a change in the charge on the complex ion.

.....

(iv) A ligand substitution reaction in which there is a large change in entropy.

.....

(8)

(c) An aqueous solution of iron(II) sulphate is a pale-green colour. When aqueous sodium hydroxide is added to this solution a green precipitate is formed. On standing in air, the green precipitate slowly turns brown.

(i) Give the formula of the complex ion responsible for the pale-green colour.

.....

(ii) Give the formula of the green precipitate.

.....

(iii) Suggest an explanation for the change in the colour of the precipitate.

.....

.....

(4)
(Total 15 marks)

Q2. (a) **P** and **Q** are oxides of Period 3 elements.

Oxide **P** is a solid with a high melting point. It does not conduct electricity when solid but does conduct when molten or when dissolved in water. Oxide **P** reacts with water forming a solution with a high pH.

Oxide **Q** is a colourless gas at room temperature. It dissolves in water to give a solution with a low pH.

(i) Identify **P**. State the type of bonding present in **P** and explain its electrical conductivity. Write an equation for the reaction of **P** with water.

(ii) Identify **Q**. State the type of bonding present in **Q** and explain why it is a gas at room temperature. Write an equation for the reaction of **Q** with water.

(9)

(b) **R** is a hydroxide of a Period 3 element. It is insoluble in water but dissolves in both aqueous sodium hydroxide and aqueous sulphuric acid.

(i) Give the name used to describe this behaviour of the hydroxide.

(ii) Write equations for the reactions occurring.

(iii) Suggest why **R** is insoluble in water.

(6)
(Total 15 marks)