1. When CuCl is dissolved in an excess of concentrated hydrochloric acid, a colourless solution containing the complex ion, $[CuCl_2]^-$, is formed. When hydrogen peroxide, H_2O_2, is added to this acidified solution, a green solution containing a copper complex ion, **X**, and water are formed. On the addition of a large excess of water, a blue solution containing the copper complex ion, **Y** is formed.

(a) Give the oxidation state of copper in $[CuCl_2]^-$, give the electronic configuration of copper in this species and deduce why it is colourless.

Oxidation state.....

Electronic configuration.....

Deduction.....

(3)

(b) Give the formula and shape of the copper complex ion **X.**

Formula.....

Shape.....

(2)

(c) State the role of hydrogen peroxide in the formation of **X**.

.....

(1)

(d) Construct a half-equation for the formation of water, as the only product, from hydrogen peroxide in acid solution.

.....

(I)

(e) Write an equation for the formation of **Y** from **X** and identify the role of water in this reaction.

Equation.....

Role of water.....

(2)

(Total 9 marks)

2. (a) Define the terms *Lewis acid* and *Brønsted Lowry acid*

Lewis acid.....

Brønsted-Lowry acid.....

(2)

(b) (i) Write an equation to show what happens when anhydrous aluminium chloride is added to an excess of water.

.....

(ii) Write an equation to show that the aluminium species formed in part (i) can behave as a Brønsted-Lowry acid.

.....

(iii) Construct an equation to show aluminium chloride acting as a Lewis acid in its reaction with concentrated hydrochloric acid.

.....

(3)

(c) Describe what you would see, and give the formulae of the iron-containing or chromium-containing products formed, when

(i) aqueous iron(III) chloride is treated with an excess of solid sodium carbonate:

Observation(s).....

.....

Formula of iron-containing product.....

(ii) aqueous chromium(III) sulphate is added to an excess of aqueous sodium hydroxide.

Observation(s).....

.....

Formula of chromium-containing product.....

(6)
(Total 11 marks)

3. When a solution of $[Ti(H_2O)_4Cl_2]^+$ ion is diluted with water, a substitution reaction occurs and the pink $[Ti(H_2O)_6]^{3+}$ ion is formed.

(i) Explain what is meant by the term *substitution reaction*.

.....

.....

(ii) Construct an equation for this reaction.

.....

.....

(iii) What change to the titanium ion is responsible for the colour change in the reaction?

.....

(3)
(Total 3 marks)

4. Study the passage below

A crystalline solid **A** dissolves in water to give a solution containing the metal complex ion **B**.

Addition of aqueous silver nitrate to this solution gives a white precipitate of **C** which dissolves when an excess of dilute aqueous ammonia is added to form a solution containing the metal complex ion **D**.

The solution of **A** becomes a blue solution containing metal complex ion **E** when an excess of concentrated hydrochloric acid is added.

When concentrated aqueous ammonia is added dropwise to a solution of **A**, a blue-green precipitate **F** forms. This then dissolves when an excess of ammonia is added to form a pale brown solution containing the metal complex ion **G**. This pale brown solution becomes dark brown on standing in air and a solution containing the metal complex ion **H** is formed.

Identify by **formula**, each of the species lettered **B – H** and finally the solid **A.**

*Formula of complex ion **B***.....

*Formula of precipitate **C***.....

*Formula of complex ion **D***.....

*Formula of complex ion **E***.....

*Formula of precipitate **F***.....

*Formula of complex ion **G***.....

*Formula of complex ion **H***.....

*Formula of starting solid **A***.....

(Total 8 marks)

5. (a) State what is meant by the term *co-ordinate bond*.

.....

.....

(2)

(b) Define the terms *Brønsted–Lowry acid* and *Lewis acid*.

Brønsted–Lowry acid .....

Lewis acid .....

(2)

(c) State what is meant by the term *bidentate ligand*.

.....

.....

(2)

(d) State how the co-ordination number of cobalt(II) ions in aqueous solution changes when an excess of chloride ions is added. Give a reason for the change.

Change in co-ordination number .....

Reason for change .....

.....

(2)

(e) Suggest why the enthalpy change for the following reaction is close to zero.

$[Co(NH_3)_6]^{2+} + 3NH_2CH_2CH_2NH_2 \rightarrow [Co(NH_2CH_2CH_2NH_2)_3]^{2+} + 6NH_3$

.....

.....

(2)

(f) Deduce the formula of the compound formed when ethane-1,2-diamine is treated with an excess of hydrochloric acid.

.....

(1)

(Total 11 marks)

6. Study the passage below and answer the questions which follow.
Crystalline iron (III) nitrate nonahydrate, $Fe(NO_3)_3.9H_2O$, has a very pale violet colour and contains the ion $[Fe(H_2O)_6]^{3+}$. When added to water, the crystals dissolve to form a brown solution. Treatment of this brown solution with concentrated nitric acid yields a very pale violet solution.

(a) Name the shape of the $[Fe(H_2O)_6]^{3+}$ ion.

.....

(1)

(b) Write an equation to show the $[Fe(H_2O)_6]^{3+}$ ion behaving as an acid in aqueous solution.

.....

(1)

(c) Deduce the formula of the species responsible for the brown colour of the solution described above.

.....

(1)

(d) Explain why the addition of concentrated nitric acid causes the colour of the solution to change from brown to very pale violet.

.....

.....

.....

(2)

(e) When concentrated hydrochloric acid is added to the brown solution of iron (III) nitrate, however, a yellow solution containing $[FeCl_4]^-$ ions is formed.
Give two reasons for a colour change in this reaction.

Reason 1.....

Reason 2.....

(2)

(f) When an excess of magnesium metal is added to an aqueous solution of iron (III) nitrate, effervescence occurs, and a brown precipitate forms. Identify the gas evolved, give the formula of the brown precipitate and construct an equation, or equations, for the reaction occurring.

Identity of gas.....

Formula of brown precipitate.....

Equation(s).....

.....

(3)
(Total 10 marks)

7. (a) Complete the electronic arrangement of the Co^{2+} ion.

[Ar] .....

(1)

(b) Give the formula of the cobalt complex present in an aqueous solution of cobalt(II) sulphate and state its colour.

Formula of cobalt complex .....

Colour of cobalt complex .....

(2)

(c) (i) When a large excess of concentrated aqueous ammonia is added to an aqueous solution of cobalt(II) sulphate, a new cobalt(II) complex is formed.
Give the formula of the new cobalt(II) complex and state its colour.

Formula of new cobalt(II) complex .....

Colour of new cobalt(II) complex .....

(ii) Write an equation for the formation of this new complex.

.....

(3)

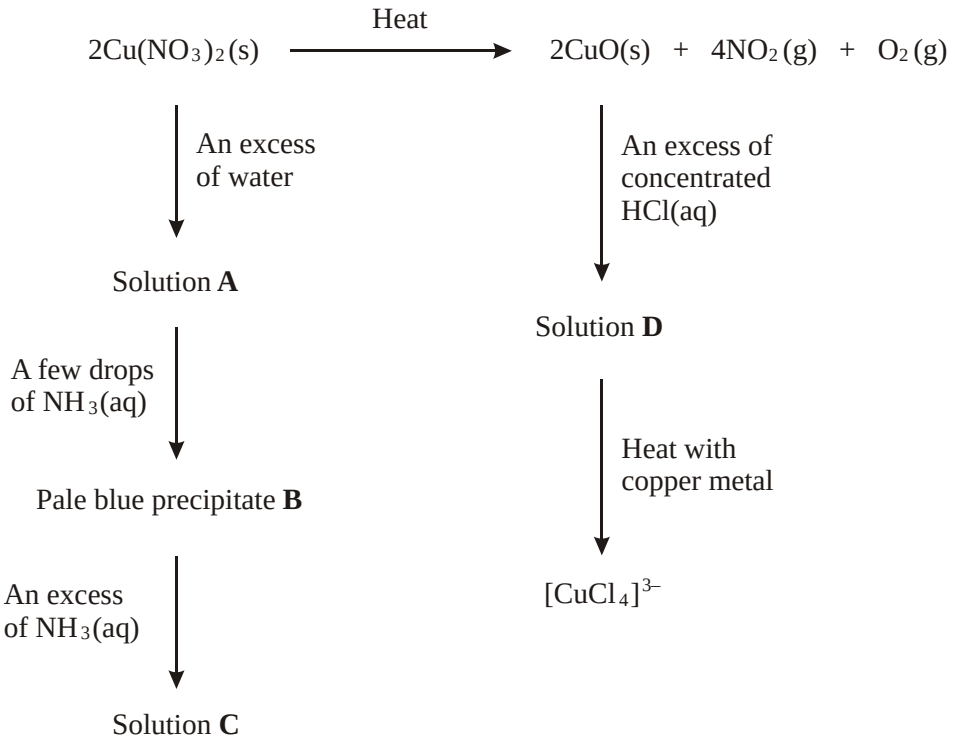
(d) When hydrogen peroxide is added to the mixture formed in part (c), the colour of the solution darkens due to the formation of a different cobalt complex. Identify this different cobalt complex and state the role of hydrogen peroxide in its formation.

Cobalt complex formed.....

Role of hydrogen peroxide .....

(2)
(Total 8 marks)

8. 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.

.....

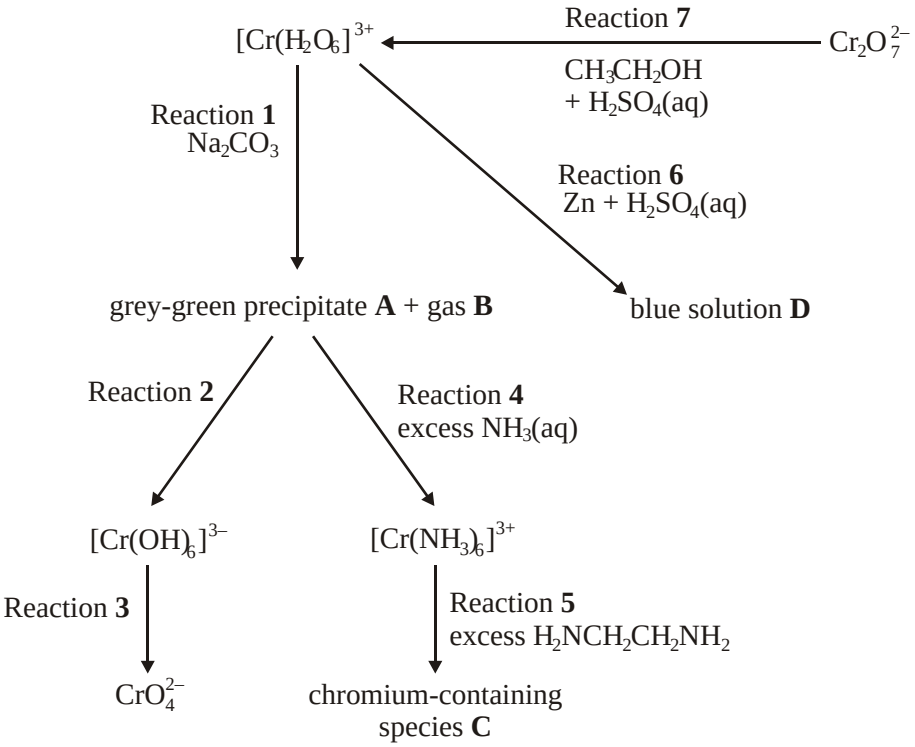
(ii) Deduce the role of copper metal in the formation of $[CuCl_4]^{3-}$ from the copper-containing species in solution **D**.

.....

(2)

(Total 17 marks)

9. The following scheme shows some reactions of chromium compounds in aqueous solution.



(a) Identify the grey-green precipitate **A** and the gas **B** formed in Reaction **1**. Write an equation for this reaction.

*Precipitate **A*** .....

*Gas **B*** .....

Equation .....

.....

(3)

(b) (i) Identify a reagent for Reaction **2**.

.....

(ii) Deduce the oxidation state of chromium in CrO_4^{2-}

.....

(iii) Identify a reagent needed for Reaction **3**. Write a half-equation for the conversion of $[Cr(OH)_6]^{3-}$ into CrO_4^{2-}

Reagent .....

Half-equation .....

(4)

(c) (i) Draw the structure of the chromium-containing species **C** formed in Reaction **5**. Indicate the charge on species **C**.

(ii) Explain, by reference to the changes in bonding, why the enthalpy change, ΔH, in Reaction **5** is close to zero.

.....

.....

(iii) Explain why the free-energy change, ΔG, for Reaction **5** is negative.

.....

.....

.....

.....

(7)

(d) Identify the chromium-containing species present in the blue solution **D** formed in Reaction **6** and state the role of zinc in its formation.

Chromium-containing species .....

Role of zinc.....

(2)

(e) Two organic compounds are formed in Reaction **7**. One of these compounds has a low boiling point and can be distilled readily from the reaction mixture. The other compound has a higher boiling point and is the main organic product formed when the reaction mixture is refluxed.

(i) Identify the organic product which has a low boiling point.

.....

(ii) Identify the main organic product formed when the mixture is refluxed.

.....

(2)

(Total 18 marks)

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

.....

.....

.....

.....

.....

(Total 4 marks)

11. (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)

12.

(i) When aqueous ammonia was added to an aqueous solution of cobalt(II) sulphate, a blue precipitate **M** was formed. Identify the cobalt-containing species present in aqueous cobalt(II) sulphate and the precipitate **M**.

Cobalt-containing species .....

*Precipitate **M*** .....

(ii) Precipitate **M** dissolved when an excess of concentrated aqueous ammonia was added. The solution formed was pale brown due to the presence of the cobalt-containing species **P**. Identify **P**.

.....

(iii) On standing in air, the colour of the solution containing **P** slowly darkened as the cobalt-containing species **Q** was formed. State the type of reaction occurring when **P** changes into **Q** and identify the reactant responsible for this change.

Type of reaction .....

Reactant responsible .....

(Total 5 marks)

13. (a) Complete the following electron configurations.

(i) Cu $1s^2 2s^2 2p^6 3s^2 3p^6$ .....

(1)

(ii) Cu^{2+} $1s^2 2s^2 2p^6 3s^2 3p^6$ .....

(1)

(b) When aqueous copper (II) sulphate is added to a large excess of concentrated hydrochloric acid, the reaction represented by the equation below takes place.

$$[Cu(H_2O)_6]^{2+}(aq) + 4Cl^-(aq) \rightleftharpoons [CuCl_4]^{2-}(aq) + 6H_2O(l)$$

(i) Name the type of bonding between the copper ion and the water molecules in the complex ion, $[Cu(H_2O)_6]^{2+}$.

.....

(1)

(ii) State the shape of each of the complex ions.

$[Cu(H_2O)_6]^{2+}$ .....

$[CuCl_4]^{2-}$ .....

(2)

(iii) Describe the colour change which would be observed as the reaction takes place.

.....

(2)

(c) (i) Describe the changes which are observed when aqueous ammonia is added dropwise, until in excess, to aqueous copper(II) sulphate.

.....

.....

(2)

(ii) Give the formula of the copper-containing complex ion which is present at the end of the changes described in (c)(i).

.....

(1)

(Total 10 marks)

14. (a) (i) What is meant by *amphoteric character* of a metal hydroxide?

.....

.....

(ii) Write two equations to show that aluminium hydroxide is amphoteric.

Equation 1 .....

.....

Equation 2 .....

.....

(5)

(b) Given a solution containing a mixture of silver nitrate and aluminium nitrate, outline how you would obtain from it a solution containing silver ions but no aluminium ions. Give the formula and shape of the silver complex ion in the solution you would obtain.

Method .....

.....

.....

.....

.....

.....

Formula of silver complex ion .....

Shape of silver complex ion .....

(5)
(Total 10 marks)

15. Solid $CuCl_2$ forms a yellow-green solution when dissolved in an excess of concentrated hydrochloric acid. When the yellow-green solution is poured into water, a blue solution is obtained. When the yellow-green solution is treated with a reducing agent, a colourless solution containing $[CuCl_2]^-$ is formed.

(i) Identify the species causing the yellow-green colour, state its shape and give the oxidation state of copper in this species.

Yellow-green species.....

Shape.....

Oxidation state of copper.....

(ii) Write an ionic equation for the formation of the blue species from the one that is yellow-green.

.....

.....

(iii) Explain why the species $[CuCl_2]^-$ is not coloured.

.....

.....

(Total 5 marks)

16. Identify, by formula, each of the species labelled **A - I** in the two reaction sequences described below.

(a) Metal **A** dissolves in dilute sulphuric acid to give a pale green solution containing the metal complex ion **B.** Treatment of **B** with sodium hydroxide solution gives a green precipitate **C.** When precipitate **C** is allowed to stand in air, it becomes a brown precipitate **D.**

Formula of metal **A**.....

Formula of complex ion **B**.....

Formula of precipitate **C**.....

Formula of precipitate **D**.....

(4)

(b) Metal **E** dissolves in dilute nitric acid to form a blue solution containing the metal complex ion **F.**
Treatment of **F** with an excess of concentrated hydrochloric acid gives a yellow-green solution containing the metal complex ion **G.**
If complex ion **F** is treated with aqueous ammonia, a blue precipitate **H** is formed.
Precipitate **H** dissolves when an excess of aqueous ammonia is added forming a dark blue solution containing the metal complex ion **I**.

*Formula of metal **E***.....

*Formula of complex ion **F***.....

*Formula of complex ion **G***.....

*Formula of precipitate **H***.....

*Formula of complex ion **I*** .....

(5)
(Total 9 marks)

17. (a) (i) Write an equation to show why aqueous chromium(III) chloride is acidic.

.....

(ii) Explain why aqueous chromium(III) chloride is more acidic than aqueous chromium(II) chloride.

.....

.....

.....

(3)

(b) The addition of sodium hydroxide or of sodium carbonate to aqueous chromium(III) chloride results in the formation of the same green precipitate.

(i) Identify this green precipitate.

.....

(ii) State the role shown by both sodium hydroxide and sodium carbonate in the formation of this green precipitate.

.....

(iii) Identify the gas evolved when carbonate ions react with aqueous chromium(III) ions and write an equation for the reaction occurring.

Gas evolved .....

Equation .....

.....

.....

(4)
(Total 7 marks)

18. Find the element gallium (Ga) in the Periodic Table and use its position to help you to answer the questions which follow.

(a) Gallium(III) chloride dissolves in water in a vigorous reaction.

(i) Write an equation for the reaction of gallium(III) chloride with water.

.....

(ii) Predict an approximate pH for the solution formed and explain your answer.

Approximate pH .....

Explanation .....

.....

(4)

(b) Predict what you would observe when a solution of gallium(I1I) chloride is treated with each of the following reagents added dropwise until in excess. Write equations for the reactions which occur.

(i) sodium carbonate

Observation(s) .....

.....

Equation(s) .....

.....

.....

(ii) sodium hydroxide

Observation(s) .....

.....

Equation(s) .....

.....

.....

(8)
(Total 12 marks)

19. (a) Define the terms *reducing agent* and *Lewis acid* in terms of electrons.

Reducing agent .....

Lewis acid .....

(2)

(b) Titanium(IV) chloride is a Lewis acid. Predict which one of the following will **not** react with titanium(IV) chloride and give a reason for your answer.

$CH_3CH_2OCH_2CH_3$ $CH_3CH_2CH_2CH_2CH_3$ $CH_3CH_2CH_2CH_2NH_2$

Prediction .....

Reason .....

(2)

(c) By giving a reagent or reagents and stating the observation with each compound, indicate how you could distinguish between the substances in each of the following pairs.

(i) $(NH_4)_2SO_4(aq)$ and $NH_4VO_3(aq)$

Reagent(s)

.....

Observation with $(NH_4)_2SO_4(aq)$

.....

Observation with $NH_4VO_3(aq)$

.....

(ii) $FeSO_4(aq)$ and $Fe_2(SO_4)_3(aq)$

Reagent(s) .....

Observation with $FeSO_4(aq)$

.....

Observation with $Fe_2(SO_4)_3(aq)$

.....

(6)

(Total 10 marks)

20.

(i) Describe what you would see if cobalt(II) chloride solution were treated with sodium hydroxide solution. Give the formula of the cobalt-containing product.

Observation(s) .....

Formula of product .....

(ii) Describe what you would see if hydrogen peroxide solution were added to the mixture produced in part (c)(i). Give the formula of the cobalt-containing product.

Observation(s) .....

Formula of product .....

(4)
(Total 4 marks)

21. (a) Give the reagents necessary to carry out each of the following conversions.

(i) $[Co(H_2O)_6]^{2+} \longrightarrow [Co(NH_3)_6]^{3+}$

.....

(ii) $[Co(H_2O)_6]^{2+} \longrightarrow [CoCl_4]^{2-}$

.....

(iii) $[Cr(H_2O)_6]^{3+} \longrightarrow [CrO_4]^{2-}$

.....

(iv) $[VO_4]^{3-} \longrightarrow [V(H_2O)_6]^{2+}$

.....

(8)

(b) Describe, with essential experimental details, how you could prepare a sample of iron(II) carbonate starting from iron(II) hydroxide.

.....

.....

.....

.....

.....

.....

(4)

(Total 12 marks)

22. An aqueous solution of a transition metal compound contains a pink species **P** which is converted into a blue species **B** when a high concentration of chloride ions is present.

Give the formulae of the species **P** and **B**, name their shapes, and write an equation for the conversion of **P** into **B**.

*Formula of **P*** .....

*Shape of **P*** .....

*Formula of **B*** .....

*Shape of **B*** .....

Equation .....

.....

(Total 5 marks)

23. When aqueous cobalt(II) chloride is treated with aqueous ammonia, a precipitate forms.

(i) Give the formula of this precipitate and write an equation, or equations, to show how it is formed.

Formula of precipitate .....

Equation(s) .....

.....

(ii) This precipitate dissolves when an excess of aqueous ammonia is added and a pale brown solution is formed. Give the formula of the cobalt species present in the pale brown solution and write an equation to show how it is formed from the precipitate.

Formula .....

Equation .....

.....

(iii) State what is observed when this pale brown solution is allowed to stand in air and give the formula of the new cobalt species formed.

Observation .....

Formula .....

(Total 8 marks)

24. (a) (i) Distinguish between the terms *Lewis base* and *reducing agent.*

.....

.....

.....

(ii) By means of an equation, in each case, show how a bromide ion can behave as a Lewis base in one reaction and as a reducing agent in another reaction.

Br^- as a Lewis base .....

.....

Br^- as a reducing agent .....

.....

(4)

(b) Describe by stating essential reagents and conditions how, starting from potassium dichromate(VI), you would obtain a solution containing each of the following ions as the only chromium species. Give an equation for the reaction in each case.

$Cr^{3+}(aq)$

Reagent(s) ……...

Conditions .....

Equation .....

.....

.....

$Cr^{2+}(aq)$

Reagent(s) ……...

Conditions .....

Equation .....

.....

.....

(9)

(c) Predict what you would observe, and give the formula of the chromium-containing product obtained in each case, when solid sodium carbonate is added to aqueous solutions of each of the following ions.

$Cr^{3+}(aq)$

Observations with Na_2CO_3 .....

Formula of chromium-containing product .....

$Cr^{2+}(aq)$

Observations with Na_2CO_3 .....

Formula of chromium-containing product .....

(5)
(Total 18 marks)

25. (a) Octahedral and tetrahedral complex ions are produced by the reaction of transition metal ions with ligands which form co-ordinate bonds with the transition metal ion.
Define the term *ligand* and explain what is meant by the term *co-ordinate bond*.

(3)

(b) (i) Some complex ions can undergo a ligand substitution reaction in which both the co-ordination number of the metal and the colour change in the reaction.
Write an equation for one such reaction and state the colours of the complex ions involved.

(ii) Bidentate ligands replace unidentate ligands in a metal complex by a ligand substitution reaction.
Write an equation for such a reaction and explain why this reaction occurs.

(8)

(c) The frequency, v, of light absorbed by a transition metal complex ion can be determined using the relationship $\Delta E = hv$. State what is meant by the symbols ΔE and h. Give **three** factors which result in a change in the frequency of light absorbed as a result of the reaction of a complex ion.

(5)
(Total 16 marks)

26. (a) Explain what is meant by a *substitution reaction* of a transition metal ion.

Describe what you would see when aqueous ammonia is added dropwise until in excess to separate solutions of copper(II) sulphate and chromium(III) sulphate.

Write equations for the reactions which occur.

(11)

(b) The ligand 1,2-diaminoethane, $NH_2CH_2CH_2NH_2$, is a bidentate ligand. For each of the following experiments, predict the formula of the final complex formed.

(i) An excess of 1,2-diaminoethane is added to an aqueous solution of copper(II) sulphate.

(ii) An excess of 1,2-diaminoethane is added to an aqueous solution of cobalt(II) sulphate and air is bubbled through the mixture.

(4)
(Total 15 marks)

27. Read the passage below. Identify each of **A**, **B, C**, **D, E**, **F**, **G, H** and **I** and write equations for all the reactions occurring.

A is a black solid which dissolves in water to form a blue solution which contains a cation **B** and an anion **C**.

The addition of aqueous ammonia to the blue solution gives initially a blue precipitate **D** which dissolves when an excess of aqueous ammonia is added giving a deep blue solution containing species **E**.

The addition of concentrated hydrochloric acid to the blue solution of **A** gives a yellow-green solution containing species **F**.

The addition of aqueous silver nitrate to the blue solution of **A** gives a cream precipitate **G**. Precipitate **G** is insoluble in dilute aqueous ammonia but dissolves forming a colourless solution containing species **H** when concentrated aqueous ammonia is added. Precipitate **G** also dissolves when an excess of an aqueous solution of sodium thiosulphate is added giving a colourless solution containing species **I**.

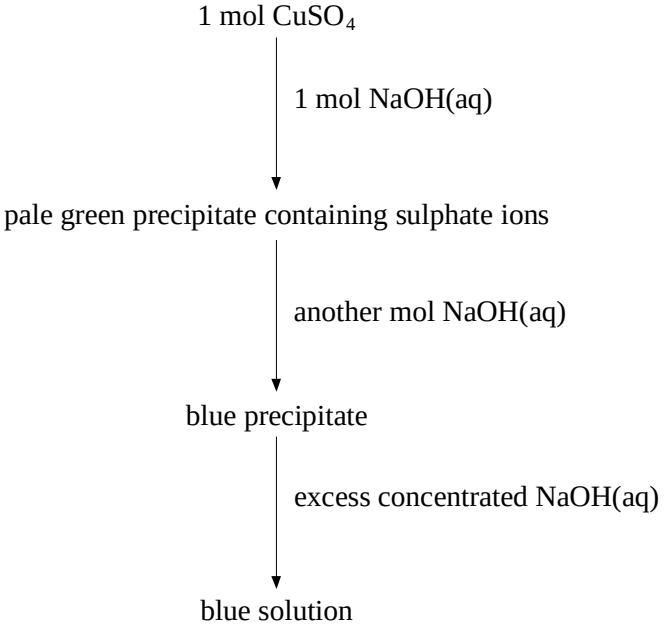
(Total 15 marks)

28. (a) Explain what is meant by the *acidity* or *hydrolysis* reaction of a metal-aqua ion.

Write equations to show that metal(II)-aqua ions and metal(III)-aqua ions are acidic. State and explain the difference in acidity between metal(II)- and metal(III)-aqua ions. Sodium carbonate gives different types of product with metal(II)- and metal(III)-aqua ions; identify the products and explain why different products are obtained.

(12)

(b) Three different products can be obtained in the reactions between aqueous copper(II) sulphate and aqueous sodium hydroxide depending on the amount of sodium hydroxide added to copper(II) sulphate. The reaction scheme is shown below.



Use your understanding of the hydrolysis reactions of metal-aqua ions to explain the formation of these three products and identify the products by formula.

(8)
(Total 20 marks)