A-Level Chemistry

Ligand Substitution

Question Paper

Time available: 69 minutes
Marks available: 63 marks

1. Solution **A** contains the compound $[Cu(H_2O)_6]Cl_2$

(a) State the type of bonding between the oxygen and hydrogen in this compound.

_____

(1)

(b) State why the chloride ions in this compound are **not** considered to be ligands.

_____

_____

_____

(1)

(c) An excess of ammonia was added to a sample of solution **A** to form solution **B**.

Write an ionic equation for the reaction that occurs when solution **A** is converted into solution **B** and state the colour of solution **B**.

Equation _____

_____

Colour _____

(2)

(d) Aqueous sodium carbonate was added to another sample of solution **A** to form a blue-green solid **C**.

Identify the blue-green solid **C**.

_____

(1)

(e) Reagent **D** was added to another sample of solution **A** to form a yellow-green solution.

Identify reagent **D** and write an ionic equation for the reaction that occurs when the yellow-green solution is formed from solution **A**.

Identity of reagent **D** _____

Equation _____

_____

(2)

(f) Explain why colorimetry cannot be used to determine the concentration of solutions containing $[CuCl_2]^-$

In your answer refer to the electron configuration of the metal ion.

(2)

(Total 9 marks)

2. Iron forms many complexes that contain iron in oxidation states +2 and +3.

(a) Hexaaquairon(III) ions react with an excess of hydrochloric acid in a ligand substitution reaction.

Write an equation for this reaction.

(1)

(b) Explain why the initial and final iron(III) complexes in the equation above have different shapes.

(2)

(c) Hexaaquairon(II) ions react with an excess of $H_2NCH_2CH_2NH_2$ in a ligand substitution reaction.

Draw the structure of the iron(II) complex formed showing its charge.

(2)

(d) Hexaaquairon(II) ions react with an excess of $H_2NCH_2CH_2NH_2$ in a ligand substitution reaction.

Which of the following shows the correct change in entropy for a reaction of hexaaquairon(II) ions with $H_2NCH_2CH_2NH_2$?

Tick (✓) **one** box.

change in entropy is negative ☐

change in entropy is close to zero ☐

change in entropy is positive ☐

(1)

(e) The percentage of iron(II) sulfate in iron tablets can be determined by titration with potassium manganate(VII) in acidic solution.

Deduce an ionic equation for the reaction of iron(II) ions with manganate(VII) ions.

_____

(1)

(f) A student dissolved 1980 mg of iron tablets in an excess of dilute sulfuric acid.
The solution was titrated with 0.0200 mol dm^{-3} potassium manganate(VII) solution. A 32.50 cm^3 volume of potassium manganate(VII) solution was required to reach the end point in the titration.

Calculate the percentage of iron in the sample of iron tablets.
Give your answer to the appropriate number of significant figures.

Percentage _____ %

(4)

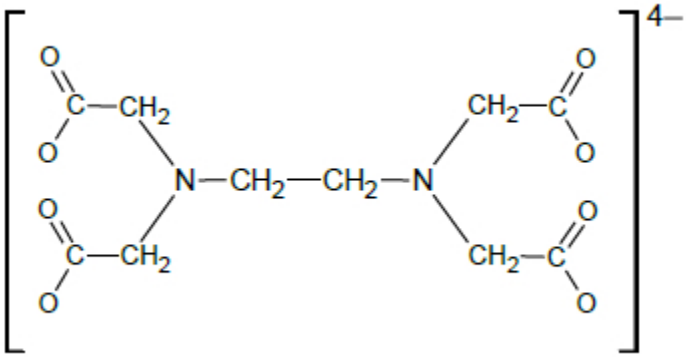
(g) State the colour change at the end point in this titration.

_____

(1)

(Total 12 marks)

3. EDTA is a useful laboratory chemical and is found in a wide variety of commercial products including detergents. It is very soluble in water and is often used in its ionic form $EDTA^{4-}$ as shown in the diagram below.



(a) $EDTA^{4-}$ can act as a multidentate ligand.

Explain the meanings of the terms **multidentate** and **ligand** with reference to the reaction of $EDTA^{4-}$ with $[Cu(H_2O)_6^{2+}](aq)$ ions to form a complex ion.

Draw on the diagram above a separate circle around each atom that bonds to the Cu^{2+} ion in this complex ion.

Multidentate _____

_____

Ligand _____

_____

(3)

(b) Copper(II) compounds may be used as fungicides in vineyards. When used in this way, copper(II) ions can enter the water supply and cause problems because they are toxic in high concentrations.

The water supply near a vineyard can be tested for copper(II) ions by forming a blue aqueous complex with $EDTA^{4-}$ ions. The concentration of this complex can be determined using a colorimeter.

Outline the practical steps that you would follow, using colorimetry, to determine the concentration of this complex in a sample of water.

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_____

_____

_____

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_____

(3)

(c) The concentration of copper(II) ions, in the sample of water, determined by colorimetry was 7.56×10^{-5} mol dm^{-3}.

This result was checked by titrating a sample of the water with a solution containing $EDTA^{4-}(aq)$ ions.

The $EDTA^{4-}(aq)$ used in the titration had a concentration of 1.00×10^{-3} mol dm^{-3}.

Write an equation for the reaction between $[Cu(H_2O)_6]^{2+}$ and $EDTA^{4-}$ ions.

Calculate the volume of the $EDTA^{4-}$ solution needed to react with a 25.0 cm^3 sample of the water.

Justify whether this titration will give an accurate value for the concentration of copper(II) ions. If necessary, suggest a practical step that would improve the accuracy.

(5)

(Total 11 marks)

4. (a) Some metal ions are toxic to humans. A substance that can be used to treat such poisoning contains the ion $EDTA^{4-}$.
$EDTA^{4-}$ forms very stable complexes with metal ions. These complexes are **not** toxic.

(i) Write an equation for the reaction of $EDTA^{4-}$ with aqueous copper(II) ions, $[Cu(H_2O)_6]^{2+}$.

(1)

(ii) A solution containing $EDTA^{4-}$ can also be used in a titration to determine the concentration of metal ions in solution.

A river was polluted with copper(II) ions. When a 25.0 cm^3 sample of the river water was titrated with a 0.0150 mol dm^{-3} solution of $EDTA^{4-}$, 6.45 cm^3 were required for complete reaction.

Calculate the concentration, in mol dm^{-3}, of copper(II) ions in the river water.
Show your working.

_____

_____

_____

_____

(2)

(b) The determination of the concentration of copper(II) ions in a single sample of river water gives an unreliable value for the copper(II) ion pollution in the river.
Give one reason why this value is unreliable.

_____

_____

(1)

(c) Silver complexes can be used to identify a particular organic functional group.
Give **one** example of a silver complex that can be used in this way and state the organic functional group it identifies.

Silver complex _____

Organic functional group _____

(2)

(Total 6 marks)

5. (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.

(4)

(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.

(4)

(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)

6.

(a) Give **one** example of a bidentate ligand.

(1)

(b) Give **one** example of a linear complex ion formed by a transition metal.

(1)

(c) Write an equation for a substitution reaction in which the complete replacement of ligands in a complex ion occurs with a change in **both** the co-ordination number and the overall charge of the complex ion.

(2)

(d) Write an equation for a substitution reaction in which the complete replacement of ligands in a complex ion occurs without a change in either the co-ordination number or the overall charge of the complex ion.

(2)

(e) When a solution containing $[Co(H_2O)_6]^{2+}$ ions is treated with a solution containing $EDTA^{4-}$ ions, a more stable complex is formed. Write an equation for this reaction and explain why the complex is more stable.

Equation _____

Explanation _____

_____

(3)

(Total 9 marks)