Q1. The redox reaction, in aqueous solution, between acidified potassium manganate(VII) and sodium ethanedioate is autocatalysed.

(a) Write an equation for this redox reaction.

Identify the species that acts as the catalyst.

Explain how the properties of the species enable it to act as a catalyst in this reaction.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(6)

(b) Sketch a graph to show how the concentration of MnO_4^- ions varies with time in this reaction.
Explain the shape of the graph.

.....

.....

.....

.....

.....

.....

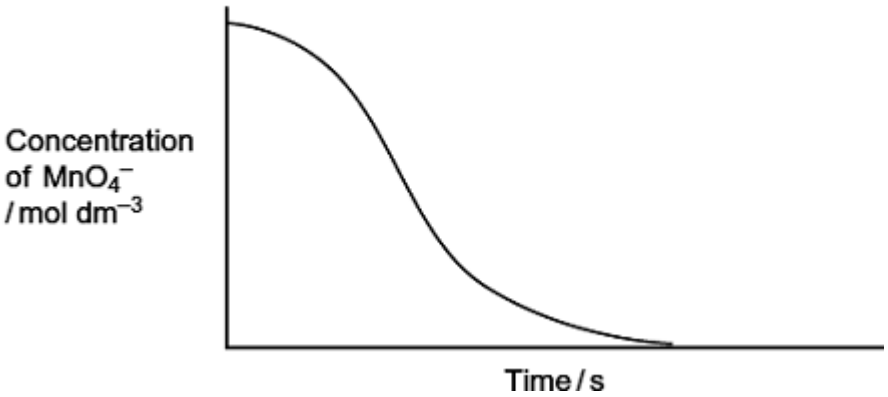
.....

.....

(4)
(Total 10 marks)

Q2. An acidified solution of potassium manganate(VII) was reacted with a sample of sodium ethanedioate at a constant temperature of 60 °C. The concentration of the manganate(VII) ions in the reaction mixture was determined at different times using a spectrometer to measure the light absorbed.

The following results were obtained.



(a) Write an equation for the reaction between manganate(VII) ions and ethanedioate ions in acidic solution.

.....

.....

.....

(Extra space) .....

.....

(2)

(b) By considering the properties of the reactants and products, state why it is possible to use a spectrometer to measure the concentration of the manganate(VII) ions in this reaction mixture.

.....

.....

.....

.....

(2)

(c) This reaction is autocatalysed. Give the meaning of the term *autocatalyst*.
Explain how the above curve indicates clearly that the reaction is autocatalysed.

Meaning of *autocatalyst* .....

.....

Explanation .....

.....

.....

.....

(3)

(d) Identify the autocatalyst in this reaction.

.....

(1)

(e) Write **two** equations to show how the autocatalyst is involved in this reaction.

Equation 1 .....

Equation 2 .....

(2)
(Total 10 marks)

Q3. When iodine molecules are dissolved in aqueous solutions containing iodide ions, they react to form triiodide ions (I_3^-).

$$I_2 + I^- \longrightarrow I_3^-$$

The reaction above between I^- ions and $S_2O_8^{2-}$ ions has a high activation energy and $S_2O_8^{2-}$ ions are only reduced slowly to SO_4^{2-} ions.
The reaction is catalysed by Fe^{2+} ions.

(a) Explain why the reaction between I^- ions and $S_2O_8^{2-}$ ions is slow.

.....

.....

.....

(1)

(b) Other than having variable oxidation states, explain why Fe^{2+} ions are good catalysts for this reaction.

.....

.....

.....

(1)

(c) Write a half-equation for the reduction of $S_2O_8^{2-}$ ions to SO_4^{2-} ions.

.....

.....

(1)

(d) Construct an overall equation for the reaction between $S_2O_8^{2-}$ ions and I^- ions.

.....

.....

.....

.....

(1)
(Total 4 marks)

Q4. Transition metal compounds have a range of applications as catalysts.

(a) State the general property of transition metals that allows the vanadium in vanadium(V) oxide to act as a catalyst in the Contact Process.

.....

(1)

(b) Write **two** equations to show how vanadium(V) oxide acts as a catalyst in the Contact Process.

Equation 1

.....

Equation 2

.....

(2)

(c) In the Contact Process, vanadium(V) oxide acts as a heterogeneous catalyst.

(i) Give the meaning of the term *heterogeneous*.

.....

.....

.....

(1)

(ii) Give **one** reason why impurities in the reactants can cause problems in processes that use heterogeneous catalysts.

.....

.....

.....

(1)

(d) The oxidation of $C_2O_4^{2-}$ ions by MnO_4^- ions in acidic solution is an example of a reaction that is autocatalysed.

(i) Give the meaning of the term *autocatalysed*.

.....

.....

.....

(1)

(ii) Identify the autocatalyst in this reaction.

.....

(1)

(iii) Write **two** equations to show how the autocatalyst is involved in this oxidation of $C_2O_4^{2-}$ ions.

Equation 1

.....

Equation 2

.....

(2)
(Total 9 marks)

Q5. This question explores some reactions and some uses of cobalt compounds.

(a) Ethanal is oxidised to ethanoic acid by oxygen. The equation for this reaction is

$$2CH_3CHO + O_2 \longrightarrow 2CH_3COOH$$

This redox reaction is slow at room temperature but speeds up in the presence of cobalt compounds.

Explain why a cobalt compound is able to act as a catalyst for this process.

Illustrate your explanation with **two** equations to suggest how, in the presence of water and hydrogen ions, Co^{3+} and then Co^{2+} ions could be involved in catalysing this reaction.

.....

.....

.....

.....

.....

.....

.....

.....

(4)

(b) In aqueous solution, the $[Co(H_2O)_6]^{2+}$ ion reacts with an excess of ethane-1,2-diamine to form the complex ion **Y**.

(i) Write an equation for this reaction.

Explain, in terms of the chelate effect, why the complex ion **Y** is formed in preference to the $[Co(H_2O)_6]^{2+}$ complex ion.

.....

.....

.....

.....

.....

.....

.....

(3)

(ii) Draw a diagram that shows the shape of the complex ion **Y** and shows the type of bond between the ethane-1,2-diamine molecules and the cobalt.

(3)

(c) Compound **Z** is a complex that contains only cobalt, nitrogen, hydrogen and chlorine.

A solid sample of **Z** was prepared by reaction of 50 cm^3 of 0.203 mol dm^{-3} aqueous cobalt(II) chloride with ammonia and an oxidising agent followed by hydrochloric acid.

When this sample of **Z** was reacted with an excess of silver nitrate, 4.22 g of silver chloride were obtained.

Use this information to calculate the mole ratio of chloride ions to cobalt ions in **Z**.

Give the formula of the complex cobalt compound **Z** that you would expect to be formed in the preparation described above.

Suggest **one** reason why the mole ratio of chloride ions to cobalt ions that you have calculated is different from the expected value.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(5)
(Total 15 marks)

Q6. An equation for the decomposition of hydrogen peroxide is

$$2H_2O_2 \longrightarrow 2H_2O + O_2$$

(a) The rate of reaction can be determined by collecting the oxygen formed and measuring its volume at regular intervals.

Draw a diagram to show the apparatus that you would use to collect and measure the volume of the oxygen formed.

(2)

(b) Explain how you could use your results from the experiment in part (a) to determine the initial rate of this reaction.

.....

.....

.....

.....

.....

(2)

(c) The rate of decomposition of hydrogen peroxide is increased by the addition of cobalt(II) ions.

Outline the essential features of an additional experiment to show that the rate of decomposition is increased by the addition of cobalt(II) chloride. Use the same method and the same apparatus as in part (a).

.....

.....

.....

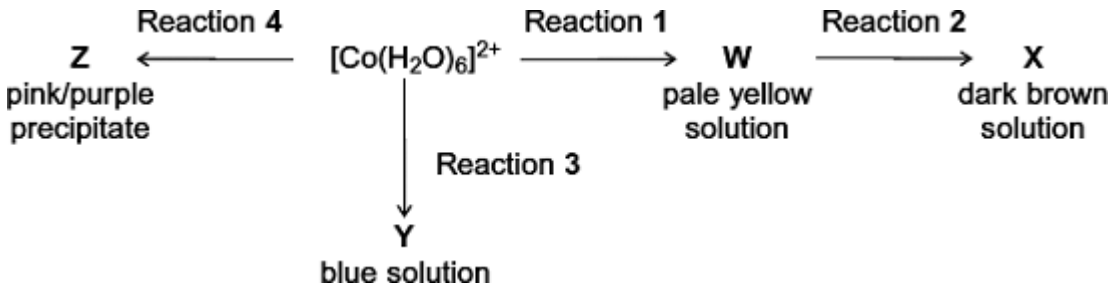
.....

.....

(2)
(Total 6 marks)

Q1. This question is about cobalt chemistry.

(a) Consider the following reaction scheme that starts from $[Co(H_2O)_6]^{2+}$ ions. **W**, **X** and **Y** are ions and **Z** is a compound.



For each of the reactions **1** to **4**, identify a suitable reagent.

Identify **W**, **X**, **Y** and **Z** and write an equation for each of reactions **1** to **4**.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

.....

(12)

(b) A flue-gas desulfurisation process involves the oxidation, by oxygen, of aqueous sulfate(IV) ions (SO_3^{2-}) into aqueous sulfate(VI) ions (SO_4^{2-}). This reaction is catalysed by Co^{2+} ions in an acidic aqueous solution.

Write an equation for the overall reaction of sulfate(IV) ions with oxygen to form sulfate(VI) ions.

Suggest why this overall reaction is faster in the presence of Co^{2+} ions.

Suggest a mechanism for the catalysed reaction by writing **two** equations involving Co^{2+} and Co^{3+} ions. You will need to use H^+ ions and H_2O to balance these two equations.

.....

.....

.....

.....

.....

.....

.....

.....

.....

(4)
(Total 16 marks)

Q2. Iron is an important element in living systems. It is involved in redox and in acid–base reactions.

(a) Explain how and why iron ions catalyse the reaction between iodide ions and $S_2O_8^{2-}$ ions. Write equations for the reactions that occur.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

.....

(5)

(b) Iron(II) compounds are used as moss killers because iron(II) ions are oxidised in air to form iron(III) ions that lower the pH of soil.

(i) Explain, with the aid of an equation, why iron(III) ions are more acidic than iron(II) ions in aqueous solution.

.....

.....

.....

.....

.....

.....

(3)

(ii) In a titration, 0.321 g of a moss killer reacted with 23.60 cm^3 of acidified 0.0218 mol dm^{-3} $K_2Cr_2O_7$ solution.

Calculate the percentage by mass of iron in the moss killer. Assume that all of the iron in the moss killer is in the form of iron(II).

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(5)

(c) Some sodium carbonate solution was added to a solution containing iron(III) ions. Describe what you would observe and write an equation for the reaction that occurs.

.....

.....

.....

.....

.....

.....

(3)

(Total 16 marks)

Q3. Transition metal ions can act as homogeneous catalysts in redox reactions. For example, iron(II) ions catalyse the reaction between peroxodisulfate ($S_2O_8^{2-}$) ions and iodide ions.

(a) State the meaning of the term *homogeneous*.

.....

(1)

(b) Suggest why ions from s block elements do **not** usually act as catalysts.

.....

.....

(1)

(c) Write an equation for the overall reaction that occurs, in aqueous solution, between $S_2O_8^{2-}$ ions and I^- ions.

.....

(1)

(d) Give **one** reason why, in the absence of a catalyst, the activation energy for the reaction between $S_2O_8^{2-}$ ions and I^- ions is high.

.....

.....

(1)

(e) Write two equations to show how Fe^{2+} ions can catalyse the reaction between $S_2O_8^{2-}$ ions and I^- ions. Suggest **one** reason why the activation energy for each of these reactions is low.

Equation 1 .....

Equation 2 .....

Reason .....

.....

(3)

(f) Explain why Fe^{3+} ions are as effective as Fe^{2+} ions in catalysing this reaction.

.....

.....

(1)

(Total 8 marks)

Q4. Three characteristic properties of transition metals are complex formation, coloured ions and catalytic activity.

(a) State the feature of transition metals that gives rise to these characteristic properties.

.....

(1)

(b) State a fourth characteristic property of transition metals.

.....

(1)

(c) For each of the following shapes of complex, identify an appropriate example by drawing its structure.

(i) a linear complex

(1)

(ii) a square planar complex

(1)

(iii) a tetrahedral complex

(1)

(d) The chemical industry makes use of the catalytic activity of transition metal compounds. For example, vanadium(V) oxide is used as a heterogeneous catalyst in the Contact Process.

(i) Write an equation for the overall reaction in the Contact Process.

.....

(1)

(ii) Explain the meaning of the term *heterogeneous* as applied to a catalyst.

.....

(1)

(iii) Write two equations to illustrate how vanadium(V) oxide acts as a catalyst in the Contact Process.

Equation 1 .....

Equation 2 .....

(2)

(iv) Suggest what is done to a heterogeneous catalyst such as vanadium(V) oxide to maximise its efficiency and how this is achieved.

.....

.....

.....

(2)

(e) The porphyrin ring is a multidentate ligand that is found in living systems complexed with iron(II) ions in haemoglobin and with cobalt(II) ions in vitamin B_{12}

(i) Give the meaning of the term *multidentate*.

.....

.....

(1)

(ii) A porphyrin ring can be represented by the symbol PR. It reacts with aqueous iron(II) ions as shown in the equation below.
The enthalpy change for this reaction is approximately zero.

$$PR(aq) + [Fe(H_2O)_6]^{2+}(aq) \rightarrow [FePR(H_2O)_2]^{2+}(aq) + 4H_2O(l)$$

Explain why the free-energy change for this reaction is negative.

.....

.....

.....

.....

(2)

(iii) In vitamin B_{12} the cobalt(II) ion is co-ordinated to a porphyrin ring, a cyanide (CN^-) ion and an additional unidentate ligand. The cyanide ion is very toxic.

Predict the co-ordination number of the cobalt ion in vitamin B_{12}
Suggest why vitamin B_{12} is **not** toxic.

Co-ordination number .....

Reason why vitamin B_{12} is **not** toxic

.....

.....

(2)
(Total 16 marks)

Q1. This question is about the use of transition metals as catalysts.

(a) State how a catalyst speeds up a chemical reaction.

.....

.....

(2)

(b) State the characteristic property of transition metals that enables them to act as catalysts in redox reactions.

.....

(1)

(c) In the Contact Process for the conversion of sulfur dioxide into sulfur trioxide, vanadium(V) oxide acts as a heterogeneous catalyst.

(i) Write **two** equations to show how the catalyst is involved in this reaction.

Equation 1 ….....

Equation 2 .....

(2)

(ii) Suggest **one** reason why poisoning reduces the effectiveness of a heterogeneous catalyst.

.....

(1)

(iii) Suggest how poisoning of a catalyst, used in an industrial process, can be minimised.

.....

(1)

(Total 7 marks)

Q2. When anhydrous iron(III) chloride is added to water the following reactions occur.

$$FeCl_3 + 6H_2O \rightarrow [Fe(H_2O)_6]^{3+} + 3Cl^-$$

$$[Fe(H_2O)_6]^{3+} + H_2O \rightarrow [Fe(H_2O)_5(OH)]^{2+} + H_3O^+$$

(a) State the type of acidity shown by $FeCl_3$ and by $[Fe(H_2O)_6]^{3+}$ in these reactions. Explain your answers.

(4)

(b) Explain why the pH of a solution of iron(II) chloride is higher than that of a solution of iron(III) chloride of the same concentration.

(2)

(c) Transition metals have variable oxidation states. This is an important factor in their ability to act as heterogeneous and homogeneous catalysts.

(i) Vanadium(V) oxide acts as a heterogeneous catalyst in the Contact Process. Write equations to show the role of vanadium(V) oxide in this process.

(ii) In aqueous solution, Fe^{2+} ions act as a homogeneous catalyst in the reaction between I^- and $S_2O_8^{2-}$ ions. Give one reason why the reaction is slow in the absence of a catalyst. Write equations to show how Fe^{2+} ions act as a catalyst for this reaction.

(7)
(Total 13 marks)

Q3. (a) State what is meant by the term *homogeneous* as applied to a catalyst.

.....

(1)

(b) (i) State what is meant by the term *autocatalysis*.

.....

.....

(ii) Identify the species which acts as an autocatalyst in the reaction between ethanedioate ions and manganate(VII) ions in acidic solution.

.....

(2)

(c) When petrol is burned in a car engine, carbon monoxide, carbon dioxide, oxides of nitrogen and water are produced. Catalytic converters are used as part of car exhaust systems so that the emission of toxic gases is greatly reduced.

(i) Write an equation for a reaction which occurs in a catalytic converter between two of the toxic gases. Identify the reducing agent in this reaction.

Equation .....

.....

Reducing agent .....

(ii) Identify a transition metal used in catalytic converters and state how the converter is constructed to maximise the effect of the catalyst.

Transition metal .....

How effect is maximised .....

.....

(5)

(d) The strength of the adsorption of reactants and products onto the surface of a transition metal helps to determine its activity as a heterogeneous catalyst.

(i) Explain why transition metals which adsorb strongly are not usually good catalysts.

.....

(ii) Explain why transition metals which adsorb weakly are not usually good catalysts.

.....

(2)
(Total 10 marks)

Q4. (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)

Q5. (a) State and explain the effect of a catalyst on the rate and on the equilibrium yield in a reversible reaction.

(5)

(b) Explain the terms *heterogeneous* and *active sites* as applied to a catalyst. Give **two** reasons why a ceramic support is used for the catalyst in catalytic converters in cars. Explain how lead poisons this catalyst.

(7)

(c) In aqueous solution, Fe^{2+} ions act as a homogeneous catalyst in the reaction between

I^- and $S_2O_8^{2-}$ ions. Give **one** reason why the reaction is slow in the absence of a catalyst. Write equations to show how Fe^{2+} ions act as a catalyst for this reaction.

(5)

(Total 17 marks)

Q6. In which one of the following reactions is a heterogeneous catalyst **not** used?

A $N_2 + 3H_2 \rightarrow 2NH_3$

B $CO + NO \rightarrow CO_2 + \frac{1}{2}N_2$

C $CO_2 + C \rightarrow 2CO$

D $SO_2 + \frac{1}{2}O_2 \rightarrow SO_3$

(Total 1 mark)

Q1. (a) Vanadium(V) oxide is used as a heterogeneous catalyst in the Contact Process.

Explain what is meant by the terms *heterogeneous* and *catalyst* and state, in general terms, how a catalyst works.

State the essential feature of vanadium chemistry which enables vanadium(V) oxide to function as a catalyst and, by means of equations, suggest how it might be involved in the Contact Process.

(7)

(b) The following method was used to determine the percentage by mass of vanadium in a sample of ammonium vanadate(V).

A solution was made up by dissolving 0.160 g of ammonium vanadate(V) in dilute sulphuric acid. The ammonium vanadate(V) formed VO_2^+ ions in this solution. When an excess of zinc was added to this solution, the VO_2^+ ions were reduced to V^{2+} ions and the zinc was oxidised to Zn^{2+} ions.

After the unreacted zinc had been removed, the solution was titrated against a 0.0200 mol dm^{-3} solution of potassium manganate(VII). In the titration, 38.5 cm^3 of potassium manganate(VII) solution were required to oxidise all vanadium(II) ions to vanadium(V) ions.

Using half-equations, construct an overall equation for the reduction of VO_2^+ to V^{2+} by zinc in acidic solution.

Calculate the percentage by mass of vanadium in the sample of ammonium vanadate(V).

(8)
(Total 15 marks)

Q2. (a) The ion $C_2O_4^{2-}$ can act as a bidentate ligand.

(i) Explain the meaning of the term *bidentate ligand*.

.....

.....

(ii) Sketch the structure of the octahedral complex ion formed by Fe^{3+} ions which contains $C_2O_4^{2-}$ as the only ligand. Include the overall charge on the complex ion.

(5)

(b) Explain the meaning of the term *chelate effect*.

.....

.....

(2)

(c) The chloride ion can act as a monodentate ligand.

(i) Deduce the formula of the linear complex formed when an excess of concentrated hydrochloric acid is added to silver chloride.

.....

(ii) Explain why metal(II) ions do not usually form octahedral complexes when chloride ions are the only ligands.

.....

(2)

(d) The concentration of $C_2O_4^{2-}$ ions can be determined by titration in acidic solution using a standard solution of potassium manganate(VII). At room temperature, the reaction proceeds very slowly at first but becomes faster after some of the manganate(VII) ions have reacted.

(i) Suggest why this reaction is very slow at first.

.....

(ii) This is an example of an autocatalytic reaction. State the meaning of the term *autocatalytic* and identify the catalyst.

Meaning of the term autocatalytic .....

Catalyst .....

(iii) Suggest how this catalyst might be involved in the reaction.

.....

.....

.....

(5)
(Total 14 marks)

Q3. (a) "The strength of adsorption onto the active sites on the surface of a heterogeneous catalyst helps to determine the activity of the catalyst."

Explain how heterogeneous catalysts work, give **one** example of a reaction catalysed in this way and discuss why different catalysts have different activities.

(8)

(b) Outline a plan of an experiment to determine the percentage of iron present as iron(III) in a solution containing $Fe^{3+}(aq)$ and $Fe^{2+}(aq)$ ions. You are provided with zinc, a standard solution of potassium dichromate(VI) and dilute sulphuric acid. Zinc can reduce $Fe^{3+}(aq)$ to $Fe^{2+}(aq)$.

Write equations for all the reactions that occur. Explain how you would use the zinc and how you would calculate the final answer.

(7)
(Total 15 marks)

Q4.

Summarised directions for recording responses to multiple completion questions			
A (i), (ii) and (iii) only	**B** (i) and (iii) only	**C** (ii) and (iv) only	**D** (iv) alone

Which of the following statements about a catalyst is / are true?

(i) It speeds up the forward reaction and slows down the reversere action.

(iii) It increases the proportion of molecules with higher energies.

(iii) A homogeneous catalyst usually acts in the solid state.

(iv) It does not alter the value of the equilibrium constant.

(Total 1 mark)

Q5. (a) The reaction between aqueous persulphate ions, $S_2O_8^{2-}(aq)$, and iodide ions, $I^-(aq)$, is catalysed by $Fe^{2+}(aq)$ ions. Suggest why this reaction has a high activation energy.
Write equations to explain the catalytic action of $Fe^{2+}(aq)$ ions.
Suggest why $V^{3+}(aq)$ ions will also act as a catalyst for this reaction but $Mg^{2+}(aq)$ ions will not.

(6)

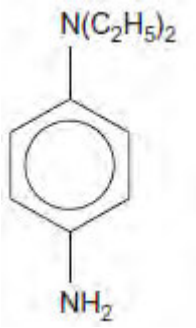
(b) Outline a mechanism for the reaction between benzene and ethanoyl chloride and explain why $AlCl_3$ acts as a Lewis acid catalyst for this reaction. Predict, with an explanation in each case, the suitability of $FeCl_3$ and of NH_4Cl to act as a catalyst for this reaction.

(9)
(Total 15 marks)

Q1. Chlorine can be found in water. One method for the determination of chlorine in water is to use colorimetry.

A colourless sample of water from a vase of flowers was analysed after the addition of compound Z as the addition of Z resulted in a purple solution.

Compound W



(a) Calculate the M_r of Compound **W**.

.....

.....

.....

(1)

(b) Determine the percentage, by mass, of nitrogen in this compound.

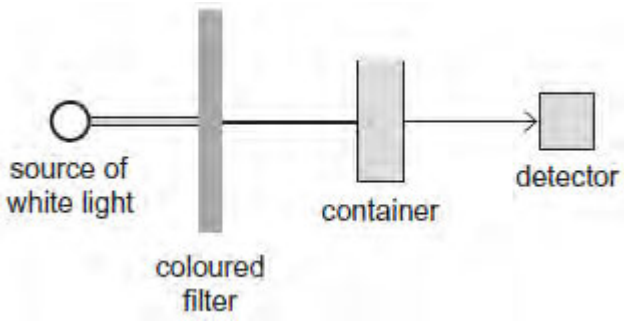
.....

.....

.....

(1)

(c) A simplified diagram of a colorimeter is shown below.



(i) Suggest why it is important that the container for each sample has the same dimensions.

.....

.....

(1)

(ii) Suggest why the coloured filter is used.

.....

.....

(1)

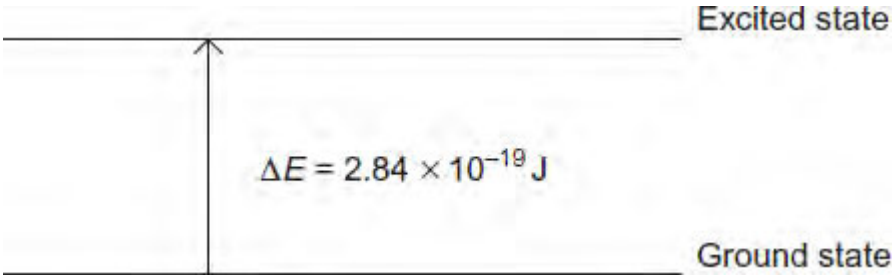
(iii) Suggest **one** reason why a colorimetric method might be chosen in preference to titration.

.....

(1)

(Total 5 marks)

Q2. This diagram represents the energy change that occurs when a d electron in a transition metal ion is excited by visible light.



(a) Give the equation that relates the energy change ΔE to the Planck constant h and the frequency of the visible light v.

Use this equation and the information in the diagram to calculate a value for the frequency of the visible light, and state the units.
The Planck constant $h = 6.63 \times 10^{-34}$ J s.

Equation .....

Calculation .....

.....

.....

.....

.....

(2)

(b) Explain why this electron transition causes a solution containing the transition metal ion to be coloured.

.....

.....

.....

.....

.....

(2)

(c) The energy change shown in the diagram represents the energy of red light and leads to a solution that appears blue.
Blue light has a higher frequency than red light.

Suggest whether the energy change ΔE will be bigger, smaller or the same for a transition metal ion that forms a red solution. Explain your answer.

Energy change .....

Explanation .....

.....

.....

.....

(2)

(d) State **three** different features of transition metal complexes that cause a change in the value of ΔE, the energy change between the ground state and the excited state of the d electrons.

Feature 1 .....

Feature 2 .....

Feature 3 .....

(3)
(Total 9 marks)

Q3. You may find the following electrode potential data helpful when answering this question.

Electrode half-equation	$E^{\ominus}$ / V
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \longrightarrow 2Cr^{3+}(aq) + 7H_2O(l)$	+1.33
$O_2(g) + 4H^+(aq) + 4e^- \longrightarrow 2H_2O(l)$	+1.23
$Cr^{3+}(aq) + e^- \longrightarrow Cr^{2+}(aq)$	–0.44
$Zn^{2+}(aq) + 2e^- \longrightarrow Zn(s)$	–0.76
$Cr^{2+}(aq) + 2e^- \longrightarrow Cr(s)$	–0.91

(a) Describe the colour changes that you would observe when an excess of zinc is added to an acidified solution of potassium dichromate(VI) in the absence of air.

For each colour change, identify the coloured ions responsible and write an equation for each reaction that occurs with zinc.
In the equations, you should represent the ions in their simplest form, for example Cr^{3+}.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

(5)

(b) Describe what you would observe when dilute aqueous sodium hydroxide is added, dropwise until in excess, to a dilute aqueous solution containing chromium(III) ions.

Write **two** equations to illustrate your observations.
In these equations you should give the full formula of each of the complexes, for example $[Cr(H_2O)_6]^{3+}$.

.....

.....

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

.....

(4)

(c) When an aqueous solution containing $[Cr(H_2O)_6]^{3+}$ ions is warmed in the presence of Cl^- ions, $[Cr(H_2O)_5Cl]^{2+}$ ions are formed and the colour of the solution changes.

Name this type of reaction.

Suggest, in terms of electrons, why the colours of the complex ions are different.

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

(3)

(d) The chromium(II) ion $[Cr(H_2O)_6]^{2+}$ has different properties from the $[Cr(H_2O)_6]^{3+}$ ion.

Use data from the table above to explain why, in an open container, $[Cr(H_2O)_6]^{2+}(aq)$ ions change into $[Cr(H_2O)_6]^{3+}(aq)$ ions.

Suggest the identity of the products formed in each case when sodium carbonate solution is added to separate solutions containing $[Cr(H_2O)_6]^{2+}(aq)$ ions and $[Cr(H_2O)_6]^{3+}(aq)$ ions.

Explain why the $[Cr(H_2O)_6]^{3+}(aq)$ ions behave differently from the $[Cr(H_2O)_6]^{2+}(aq)$ ions.

In your answer to this part of the question, equations are **not** required.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

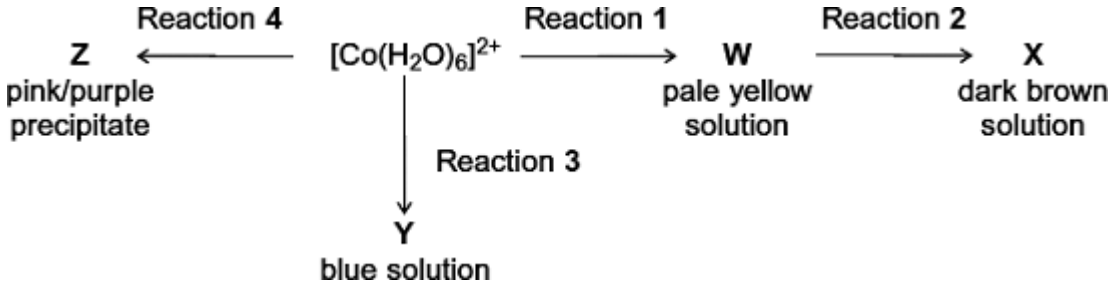
.....

.....

(7)
(Total 19 marks)

Q4. This question is about cobalt chemistry.

(a) Consider the following reaction scheme that starts from $[Co(H_2O)_6]^{2+}$ ions.
W, **X** and **Y** are ions and **Z** is a compound.



For each of the reactions **1** to **4**, identify a suitable reagent.

Identify **W**, **X**, **Y** and **Z** and write an equation for each of reactions **1** to **4**.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

.....

(12)

(b) A flue-gas desulfurisation process involves the oxidation, by oxygen, of aqueous sulfate(IV) ions (SO_3^{2-}) into aqueous sulfate(VI) ions (SO_4^{2-}). This reaction is catalysed by Co^{2+} ions in an acidic aqueous solution.

Write an equation for the overall reaction of sulfate(IV) ions with oxygen to form sulfate(VI) ions.

Suggest why this overall reaction is faster in the presence of Co^{2+} ions.

Suggest a mechanism for the catalysed reaction by writing **two** equations involving Co^{2+} and Co^{3+} ions. You will need to use H^+ ions and H_2O to balance these two equations.

.....

.....

.....

.....

.....

.....

.....

.....

.....

(4)
(Total 16 marks)

Q1.(a) The concentration of iron(III) ions in a dilute solution can be determined by visible spectrometry. The absorption of light by a number of solutions of iron(III) sulfate, $Fe_2(SO_4)_3(aq)$, was measured. The results are shown in the table below.

Concentration of $Fe_2(SO_4)_3(aq)$ / mol dm^{-3}	**Absorbance / %**
0.020	2.2
0.040	4.7
0.060	7.0
0.080	9.4
0.100	11.8

(i) Use these results to plot a graph of percentage absorbance (y-axis) against concentration of iron(III) sulfate solution on the grid below.
Draw a straight line of best fit.



(2)

(ii) Use your graph to determine the concentration of iron(III) ions in a solution of $Fe_2(SO_4)_3$ that has an absorbance of 5.4%.

.....

.....

.....

(2)

(iii) Calculate the volume of water that should be added to 100 cm^3 of a 0.10 mol dm^{-3} solution of iron(III) sulfate to make a 0.040 mol dm^{-3} solution.
Show your working.

.....

.....

.....

.....

(2)

(b) Give **one** reason why well-water may be more beneficial to health than pure water.

.....

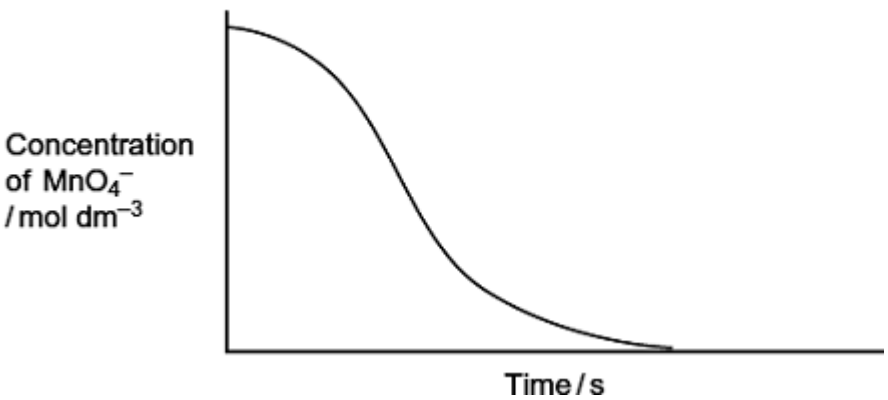
.....

.....

(1)
(Total 7 marks)

Q2. An acidified solution of potassium manganate(VII) was reacted with a sample of sodium ethanedioate at a constant temperature of 60 °C. The concentration of the manganate(VII) ions in the reaction mixture was determined at different times using a spectrometer to measure the light absorbed.

The following results were obtained.



(a) Write an equation for the reaction between manganate(VII) ions and ethanedioate ions in acidic solution.

.....

.....

.....

(Extra space) .....

.....

(2)

(b) By considering the properties of the reactants and products, state why it is possible to use a spectrometer to measure the concentration of the manganate(VII) ions in this reaction mixture.

.....

.....

.....

.....

(2)

(c) This reaction is autocatalysed. Give the meaning of the term *autocatalyst*. Explain how the above curve indicates clearly that the reaction is autocatalysed.

Meaning of *autocatalyst* .....

.....

Explanation .....

.....

.....

.....

(3)

(d) Identify the autocatalyst in this reaction.

.....

(1)

(e) Write **two** equations to show how the autocatalyst is involved in this reaction.

Equation 1 .....

Equation 2 .....

(2)

(Total 10 marks)

Q3. This question is about copper chemistry.

(a) Aqueous copper(II) ions $[Cu(H_2O)_6]^{2+}(aq)$ are blue.

(i) With reference to electrons, explain why aqueous copper(II) ions are blue.

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

.....

(3)

(ii) By reference to aqueous copper(II) ions, state the meaning of each of the **three** terms in the equation $\Delta E = h\nu$.

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

.....

(3)

(iii) Write an equation for the reaction, in aqueous solution, between $[Cu(H_2O)_6]^{2+}$ and an excess of chloride ions.
State the shape of the complex produced and explain why the shape differs from that of the $[Cu(H_2O)_6]^{2+}$ ion.

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

.....

(3)

(b) Draw the structure of the ethanedioate ion ($C_2O_4^{2-}$).
Explain how this ion is able to act as a ligand.

.....

.....

.....

.....

.....

(2)

(c) When a dilute aqueous solution containing ethanedioate ions is added to a solution containing aqueous copper(II) ions, a substitution reaction occurs. In this reaction four water molecules are replaced and a new complex is formed.

(i) Write an ionic equation for the reaction. Give the co-ordination number of the complex formed and name its shape.

.....

.....

.....

.....

.....

.....

(4)

(ii) In the complex formed, the two water molecules are opposite each other. Draw a diagram to show how the ethanedioate ions are bonded to a copper ion and give a value for one of the O–Cu–O bond angles. You are **not** required to show the water molecules.

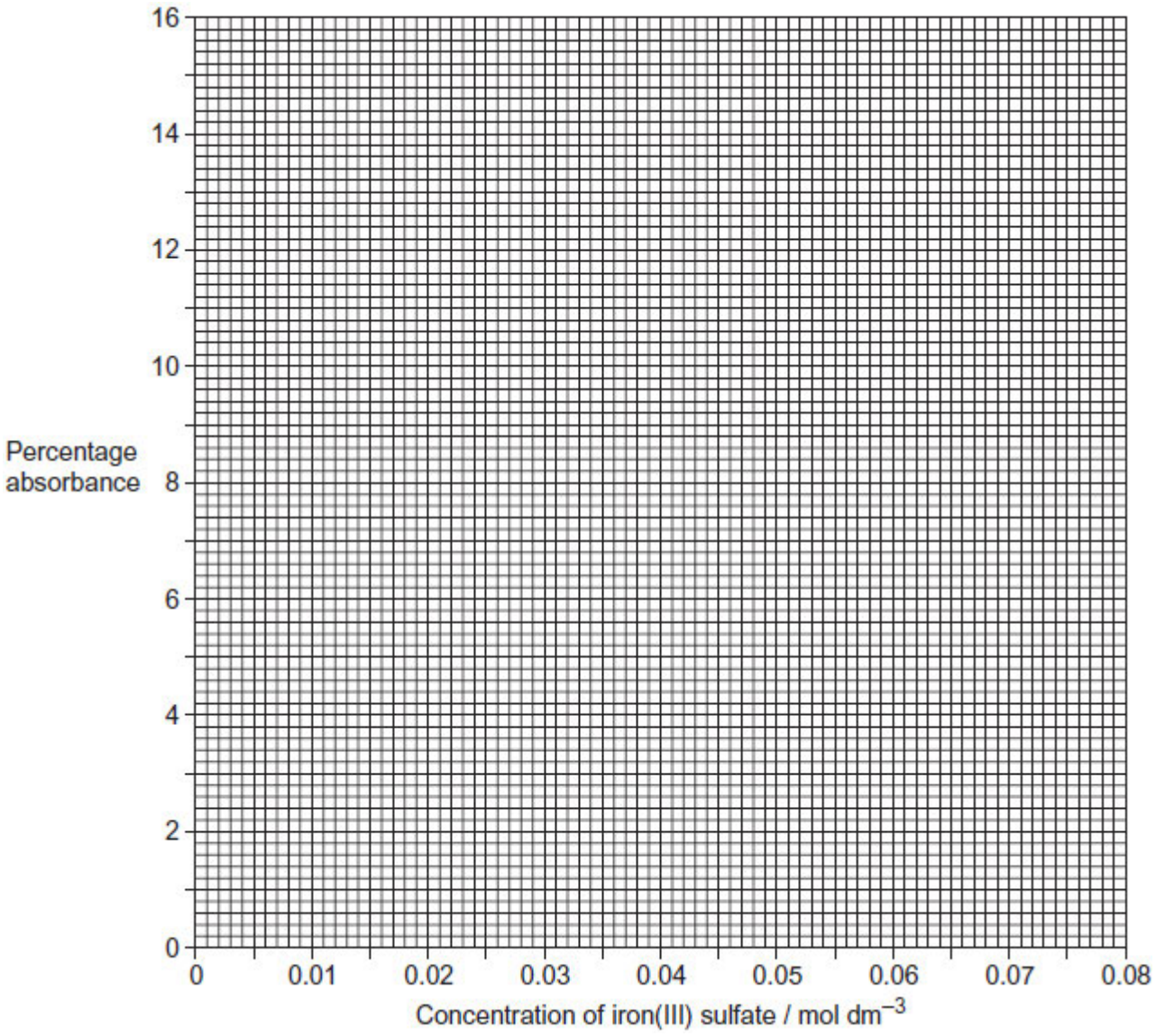
(2)
(Total 17 marks)

Q4. The concentration of iron(III) ions in a dilute solution can be determined by visible spectrometry. The absorption of light of a particular frequency by solutions of iron(III) sulfate of different concentrations was measured. The results are shown in the table

below.

Percentage absorbance	Concentration of iron(III) sulfate / mol dm^{-3}
1.0	7.5×10^{-3}
2.5	14.0×10^{-3}
5.0	27.5×10^{-3}
7.0	37.5×10^{-3}
10.0	54.0×10^{-3}
12.0	65.0×10^{-3}

(a) Use these results to plot a graph of percentage absorbance (y-axis) against concentration of iron(III) sulfate on the grid below.
Draw a straight line of best fit.



(2)

(b) Use your graph to determine the concentration of an iron(III) sulfate solution that has a percentage absorbance of 14.0%.

.....

(1)
(Total 3 marks)

Q1. Hydrogen peroxide is used as an oxidising agent in the preparation of transition metal complexes.

(a) Consider the following reaction scheme. All the complexes are in aqueous solution.

$$[Co(H_2O)_6]^{2+} \xrightarrow{\text{Reaction 1}} \text{cobalt(II) complex} \xrightarrow[H_2O_2]{\text{Reaction 2}} [Co(NH_3)_6]^{3+}$$

(i) Identify a reagent for Reaction **1** and describe the colour change that occurs.

.....

.....

.....

.....

(3)

(ii) State the colour of the final solution formed in Reaction **2**.

.....

(1)

(b) Consider the following reaction scheme. All the complexes are in aqueous solution.

$$[Cr(H_2O)_6]^{3+} \xrightarrow[\text{Excess NaOH(aq)}]{\text{Reaction 3}} \text{chromium(III) complex} \xrightarrow[H_2O_2]{\text{Reaction 4}} CrO_4^{2-}$$

(i) For Reaction **3**, state the colour of the initial and of the final solution and write an equation for the reaction.

.....

.....

.....

.....

(4)

(ii) Write a half-equation for the reduction of hydrogen peroxide to hydroxide ions.

Deduce an overall equation for Reaction **4** and state the colour of the final

solution.

.....

.....

.....

.....

.....

.....

(4)

(c) The concentration of a hydrogen peroxide solution can be determined by titration with acidified potassium manganate(VII) solution. In this reaction the hydrogen peroxide is oxidised to oxygen gas.

A 5.00 cm^3 sample of the hydrogen peroxide solution was added to a volumetric flask and made up to 250 cm^3 of aqueous solution. A 25.0 cm^3 sample of this diluted solution was acidified and reacted completely with 24.35 cm^3 of 0.0187 mol dm^{-3} potassium manganate(VII) solution.

Write an equation for the reaction between acidified potassium manganate(VII) solution and hydrogen peroxide.
Use this equation and the results given to calculate a value for the concentration, in mol dm^{-3}, of the original hydrogen peroxide solution.
(If you have been unable to write an equation for this reaction you may assume that 3 mol of $KMnO_4$ react with 7mol of H_2O_2. This is **not** the correct reacting ratio.)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(5)
(Total 17 marks)

Q2. Calcium fluoride occurs naturally as the mineral fluorite, a very hard crystalline solid that is almost insoluble in water and is used as a gemstone.

Tables 1 and **2** contain thermodynamic data.

Table 1

Process	$\Delta H^{\ominus}$ / kJ mol^{-1}
$Ca(s) \rightarrow Ca(g)$	+193
$Ca(g) \rightarrow Ca^{+}(g) + e^{-}$	+590
$Ca^{+}(g) \rightarrow Ca^{2+}(g) + e^{-}$	+1150
$F_2(g) \rightarrow 2F(g)$	+158
$F(g) + e^{-} \rightarrow F^{-}(g)$	–348

Table 2

Name of enthalpy change	$\Delta H^{\ominus}$ / kJ mol^{-1}
Enthalpy of lattice dissociation for calcium fluoride	+2602
Enthalpy of lattice dissociation for calcium chloride	+2237
Enthalpy of hydration for F^- ions	–506
Enthalpy of hydration for Cl^- ions	–364
Enthalpy of hydration for Ca^{2+} ions	–1650

(a) Write an equation, including state symbols, for the process that occurs when the calcium fluoride lattice dissociates and for which the enthalpy change is equal to the lattice enthalpy.

.....

(1)

(b) (i) Define the term *standard enthalpy of formation*.

.....

.....

.....

.....

(3)

(ii) Write an equation, including state symbols, for the process that has an enthalpy change equal to the standard enthalpy of formation of calcium fluoride.

.....

(1)

(iii) Use data from the **Tables 1** and **2** to calculate the standard enthalpy of formation for calcium fluoride.

.....

.....

.....

.....

.....

.....

(3)

(c) Explain why the enthalpy of lattice dissociation for calcium fluoride is greater than that for calcium chloride.

.....

.....

.....

.....

(2)

(d) Calcium chloride dissolves in water. After a certain amount has dissolved, a saturated solution is formed and the following equilibrium is established.

$$CaCl_2(s) \rightleftharpoons Ca^{2+}(aq) + 2Cl^-(aq)$$

(i) Using data from **Table 2**, calculate the enthalpy change for this reaction.

.....

.....

.....

.....

.....

.....

(2)

(ii) Predict whether raising the temperature will increase, decrease or have no effect on the amount of solid calcium chloride that can dissolve in a fixed mass of water.
Explain your prediction.
(If you have been unable to obtain an answer to part (d) (i), you may assume that the enthalpy change = –60 kJ mol^{-1}. This is **not** the correct answer.)

Effect on amount of solid that can dissolve .....

Explanation .....

.....

.....

.....

(3)

(e) Calcium fluoride crystals absorb ultra-violet light. Some of the energy gained is given out as visible light. The name of this process, fluorescence, comes from the name of the mineral, fluorite.

Use your knowledge of the equation $\Delta E = h\nu$ to suggest what happens to the electrons in fluorite when ultra-violet light is absorbed and when visible light is given out.

.....

.....

.....

.....

(2)

(Total 17 marks)

Q3. Transition elements form complex ions with a range of colours and shapes.

(a) By considering its electron arrangement, state how an element can be classified as a transition element.

.....

.....

(1)

(b) Explain the meaning of the term *complex ion*.

.....

.....

.....

(2)

(c) In terms of electrons, explain why an aqueous solution of cobalt(II) sulfate has a red colour.

.....

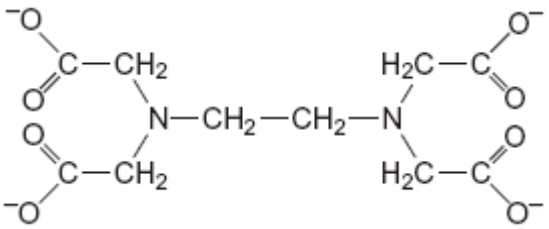
.....

.....

.....

(3)

(d) The ligand $EDTA^{4-}$ is shown below.



(i) Draw circles around the atoms of **two** different elements that link to a transition metal ion by a co-ordinate bond when $EDTA^{4-}$ behaves as a ligand.

(2)

(ii) Write an equation for the reaction between $EDTA^{4-}$ and a $[Co(H_2O)_6]^{2+}$ ion. Use the abbreviation $EDTA^{4-}$ in your equation.

.....

(1)

(iii) Explain why the complex ion, formed as a product of the reaction in part (d) (ii), is more stable than the $[Co(H_2O)_6]^{2+}$ ion.

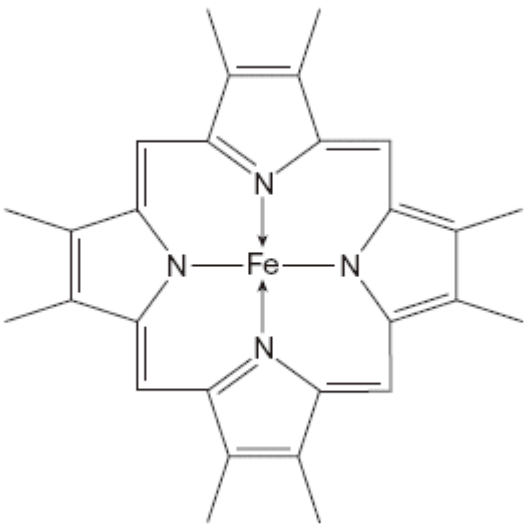
.....

.....

.....

(2)

(e) The diagram below shows part of the structure of haemoglobin.



Haemoglobin contains an iron(II) ion bonded to five nitrogen atoms and one other ligand. The fifth nitrogen atom and the additional ligand are not shown in this

diagram.

(i) In this diagram, bonds between nitrogen and iron are shown as N→Fe and as N—Fe.

State the meaning of each of these symbols.

Meaning of → ….....

Meaning of — .....

(2)

(ii) State the function of haemoglobin in the blood.

.....

(1)

(iii) With reference to haemoglobin, explain why carbon monoxide is toxic.

.....

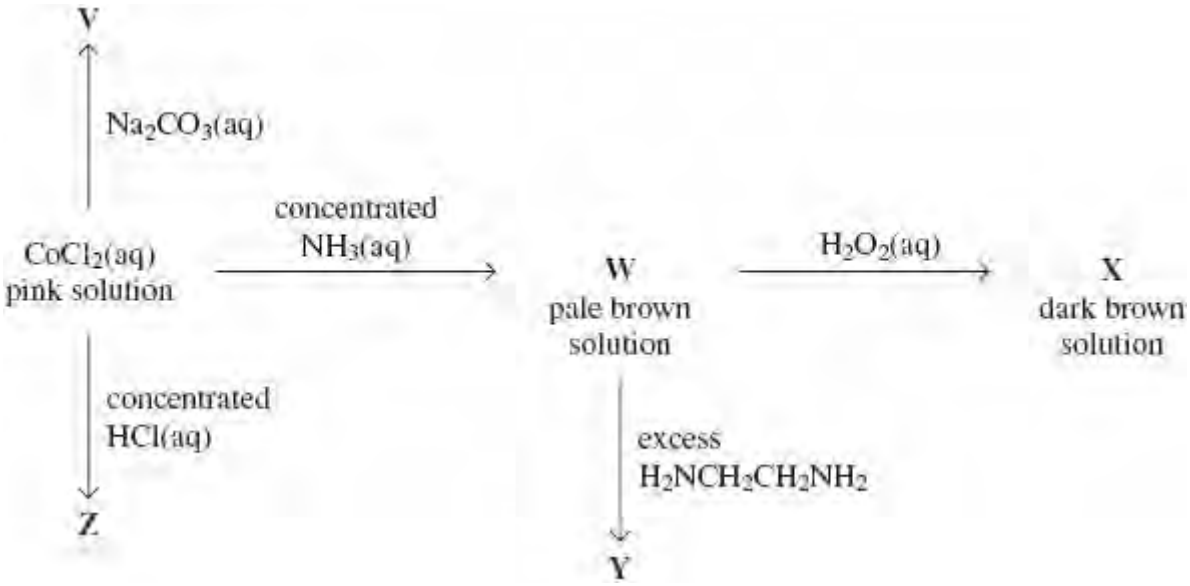
.....

.....

(2)

(Total 16 marks)

Q1. This question is about some reactions of cobalt compounds.



(a) Give the formula of the complex responsible for the pink colour in aqueous $CoCl_2$ and name its shape.

Formula .....

Name of shape .....

(2)

(b) Give the formula of the cobalt-containing compound **V** and describe its appearance.

Formula .....

Appearance .....

(2)

(c) Write an equation for the reaction that occurs when the pink solution is converted into **W**.

.....

(2)

(d) Give the formula of the cobalt-containing complex in **X** and state the role of the H_2O_2 in this reaction.

Formula .....

Role of H_2O_2 .....

(2)

(e) Give the formula of the cobalt-containing complex in **Y** and explain why this complex is more stable than the cobalt-containing complex in **W**.

Formula .....

Explanation .....

.....

.....

(3)

(f) Identify the cobalt-containing complex in solution **Z** and explain why its co-ordination number is different from that in the pink solution of $CoCl_2$

Complex .....

Explanation .....

.....

(2)
(Total 13 marks)

Q2. (a) State the electron configuration of a Ti(III) ion and that of a Ti(IV) ion. Explain, in terms of electron configurations and electron transitions, why Ti(III) compounds are usually coloured but Ti(IV) compounds are colourless.

.....

.....

.....

.....

.....

.....

.....

.....

.....

(5)

(b) Transition metal ions and their complexes can often be identified from their colours. For each of the following, identify a complex ion responsible for the colour of the aqueous solution. Restrict your answers to complexes formed from the elements Cr, Fe, Co and Cu.

A deep blue solution formed in an excess of concentrated aqueous ammonia.

A green solution formed in an excess of aqueous sodium hydroxide.

A yellow–green solution formed in an excess of concentrated hydrochloric acid.

.....

.....

.....

.....

.....

.....

(3)

(c) An experiment is carried out to investigate the rate of the autocatalysed reaction between aqueous potassium manganate(VII) and ethanedioate ions in an excess of dilute sulfuric acid. When these reagents are mixed together, the colour of the reaction mixture gradually fades. The concentration of the manganate(VII) ions is recorded at different times using a spectrometer. The temperature of the reaction mixture is constant.

(i) Give **two** reasons why the use of a spectrometer is the most appropriate method for measuring the concentration of the coloured ions in this experiment.

.....

.....

.....

.....

(2)

(ii) Sketch a curve to show how you would expect the concentration of manganate(VII) ions to change with time until the colour has faded because the concentration has reached a very low value. Explain the shape of the curve.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(5)
(Total 15 marks)

Q3. (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)

Q4. The characteristic properties of transition metals include complex formation and the formation of coloured ions.

(a) Some complex ions can undergo a ligand substitution reaction in which both the coordination number of the metal and the colour of complex ions change in the reaction.

Write an equation for one such reaction and state the colours of the complex ions involved.

Equation .....

.....

Colours of complex ions .....

.....

(4)

(b) The frequency, *v*, of light absorbed by a transition–metal complex ion can be determined using the relationship $\Delta E = hv$.

(i) State what is meant by the symbols ΔE and *h*.

Meaning of symbol ΔE .....

Meaning of symbol h .....

(ii) Give three factors which may cause the frequency of light absorbed to change when a complex ion reacts.

Factor 1 .....

Factor 2 .....

Factor 3 .....

(5)
(Total 9 marks)

Q1. (a) State the origin of the colour of transition-metal complexes.

.....

.....

(2)

(b) Give **three** changes to a transition-metal complex which result in a change in colour.

Change 1 .....

Change 2 .....

Change 3 ….....

.....

(3)

(c) You are provided with a 1.00 mol dm^{-3} solution of iron(III) ions and a visible-light spectrophotometer (colorimeter). Outline a plan for experiments using this solution and this apparatus which would enable you to determine the concentration of iron(III) ions in a solution of unknown concentration.

.....

.....

.....

.....

.....

.....

.....

.....

(5)
(Total 10 marks)

Q1. Which one of the following electronic configurations is that of a transition element?

A [Ar] $4s^2 3d^{10}$

B [Ar] $4s^2 3d^9$

C [A] $4s^2 3d^0$

D [Ar] $4s^2 3d^{10} 4p^1$

(Total 1 mark)

Q2. Which of the species given below can behave as ligands?

NH_2^- NH_3 NH_4^+

A all three

B only NH_3

C NH_3 and NH_4^+

D NH_2^- and NH_3

(Total 1 mark)

Q3. (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)

Q4.

Summarised directions for recording responses to multiple completion questions			
A (i), (ii) and (iii) only	**B** (i) and (iii) only	**C** (ii) and (iv) only	**D** (iv) alone

In which of the following conversions is the copper reduced?

(i) $[Cu(H_2O)_6]^{2+} \rightarrow [CuCl_4]^{2-}$

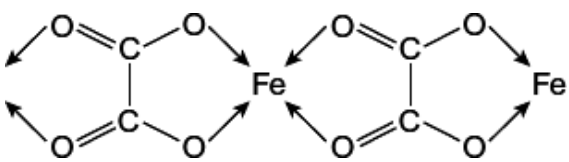
(ii) $[Cu(H_2O)_6]^{2+} \rightarrow Cu(H_2O)_4(OH)_2$

(iii) $Cu \rightarrow CuCl_2$

(iv) $[Cu(H_2O)_6]^{2+} \rightarrow CuCl$

(Total 1 mark)

Q5. Solid iron(II) ethanedioate dihydrate ($FeC_2O_4.2H_2O$) has a polymeric structure.
Two repeating units in the polymer chain are shown.



Each iron ion is also bonded to two water molecules. These are **not** shown in the diagram.

(a) Name the type of bond that is represented by the arrows.

.....

(1)

(b) In terms of electrons explain how the water molecules, **not** shown in the diagram, form bonds to the iron.

.....

.....

.....

.....

(2)

(c) Predict the value of the bond angle between the two bonds to iron that are formed by these two water molecules.

.....

(1)

(d) Iron(II) ethanedioate dihydrate can be analysed by titration using potassium manganate(VII) in acidic solution. In this reaction, manganate(VII) ions oxidise iron(II) ions and ethanedioate ions.

A 1.381 g sample of impure $FeC_2O_4.2H_2O$ was dissolved in an excess of dilute sulfuric acid and made up to 250 cm^3 of solution.
25.0 cm^3 of this solution decolourised 22.35 cm^3 of a 0.0193 mol dm^{-3} solution of potassium manganate(VII).

(i) Use the half-equations given below to calculate the reacting ratio of moles of manganate(VII) ions to moles of iron(II) ethanedioate.

$$MnO_4^- + 8H^+ + 5e^- \longrightarrow Mn^{2+} + 4H_2O$$

$$Fe^{2+} \longrightarrow Fe^{3+} + e^-$$

$$C_2O_4^{2-} \longrightarrow 2CO_2 + 2e^-$$

.....

.....

.....

(1)

(ii) Calculate the percentage by mass of $FeC_2O_4.2H_2O$ in the original sample.

(If you have been unable to answer part (d)(i) you may assume that three moles of manganate(VII) ions react with seven moles of iron(II) ethanedioate. This is **not** the correct ratio.)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(5)
(Total 10 marks)

Q6. Transition metal ions can act as homogeneous catalysts in redox reactions. For example, iron(II) ions catalyse the reaction between peroxodisulfate ($S_2O_8^{2-}$) ions and iodide ions.

(a) State the meaning of the term *homogeneous*.

.....

(1)

(b) Suggest why ions from s block elements do **not** usually act as catalysts.

.....

.....

(1)

(c) Write an equation for the overall reaction that occurs, in aqueous solution, between $S_2O_8^{2-}$ ions and I^- ions.

.....

(1)

(d) Give **one** reason why, in the absence of a catalyst, the activation energy for the reaction between $S_2O_8^{2-}$ ions and I^- ions is high.

.....

.....

(1)

(e) Write two equations to show how Fe^{2+} ions can catalyse the reaction between $S_2O_8^{2-}$ ions and I^- ions. Suggest **one** reason why the activation energy for each of these reactions is low.

Equation 1 .....

Equation 2 .....

Reason .....

.....

(3)

(f) Explain why Fe^{3+} ions are as effective as Fe^{2+} ions in catalysing this reaction.

.....

.....

(1)
(Total 8 marks)

Q7. Due to their electron arrangements, transition metals have characteristic properties including catalytic action and the formation of complexes with different shapes.

(a) Give **two other** characteristic properties of transition metals. For each property,illustrate your answer with a transition metal of your choice.

.....

.....

.....

.....

.....

.....

.....

.....

(4)

(b) Other than octahedral, there are several different shapes shown by transition metal complexes. Name **three** of these shapes and for each one give the formula of a complex with that shape.

.....

.....

.....

.....

.....

.....

.....

.....

.....

(6)

(c) It is possible for Group 2 metal ions to form complexes. For example, the $[Ca(H_2O)_6]^{2+}$ ion in hard water reacts with $EDTA^{4-}$ ions to form a complex ion in a similar manner to hydrated transition metal ions. This reaction can be used in a titration to measure the concentration of calcium ions in hard water.

(i) Write an equation for the equilibrium that is established when hydrated calcium ions react with $EDTA^{4-}$ ions.

.....

(1)

(ii) Explain why the equilibrium in part (c)(i) is displaced almost completely to the right to form the EDTA complex.

.....

.....

.....

.....

.....

.....

(3)

(iii) In a titration, 6.25 cm^3 of a 0.0532 mol dm^{-3} solution of EDTA reacted completely with the calcium ions in a 150 cm^3 sample of a saturated solution of calcium hydroxide.
Calculate the mass of calcium hydroxide that was dissolved in 1.00 dm^3 of the calcium hydroxide solution.

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

.....

(3)
(Total 17 marks)

Q8. Transition metals and their complexes have characteristic properties.

(a) Give the electron configuration of the Zn^{2+} ion.

Use your answer to explain why the Zn^{2+} ion is **not** classified as a transition metal ion.

Electron configuration .....

Explanation .....

.....

(2)

(b) In terms of bonding, explain the meaning of the term *complex*.

.....

.....

.....

.....

(2)

(c) Identify **one** species from the following list that does **not** act as a ligand. Explain your answer.

H_2 O^{2-} O_2 CO

Not a ligand.....

Explanation .....

(2)

(d) The element palladium is in the d block of the Periodic Table. Consider the following palladium compound which contains the sulfate ion.

$[Pd(NH_3)_4]SO_4$

(i) Give the oxidation state of palladium in this compound.

.....

(1)

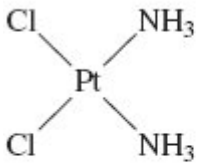
(ii) Give the names of two possible shapes for the complex palladium ion in this compound.

Shape 1 .....

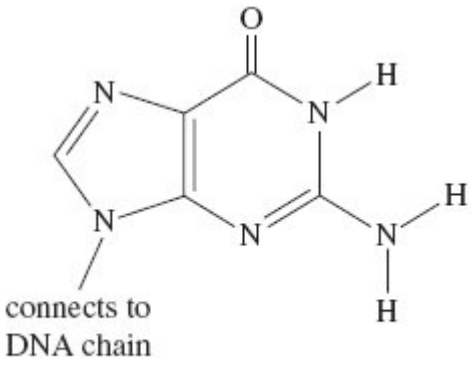
Shape 2 .....

(2)
(Total 9 marks)

Q1. The complex cisplatin acts as an anticancer drug by changing the properties of DNA when it reacts with guanine, a component of DNA.



cisplatin



guanine

When cisplatin is absorbed into the human body, it undergoes a ligand substitution reaction and one chloride ligand is replaced by a water molecule forming a complex ion **Q**.

(a) Write an equation for this substitution reaction to form the complex ion **Q**.

.....

(2)

(b) The complex ion **Q** can bond to guanine in two different ways.

(i) The first way involves a hydrogen atom, from one of the ammonia ligands on **Q**, bonding to an atom in a guanine molecule. State the type of bond formed to guanine and identify an atom in guanine that could form a bond to this hydrogen atom.

Type of bond .....

Atom in guanine .....

(2)

(ii) The second way involves a ligand substitution reaction in which an atom in a guanine molecule bonds to platinum by displacing the water molecule from **Q**. State the type of bond formed between guanine and platinum when a water molecule is displaced and identify an atom in guanine that could bond to platinum in this way.

Type of bond .....

Atom in guanine .....

(2)

(c) State and explain **one** risk associated with the use of cisplatin as an anticancer drug.

Risk .....

Explanation .....

(2)
(Total 8 marks)

Q2. (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)

Q3. A 0.263 g sample of impure iron, containing an unreactive impurity, was reacted with an excess of hydrochloric acid. All of the iron in the sample reacted, evolving hydrogen gas and forming a solution of iron(II) chloride. The volume of hydrogen evolved was 102 cm^3, measured at 298 K and 110 kPa.

The percentage, by mass, of iron in the sample can be determined using either the volume of hydrogen produced or by titrating the solution of iron(II) chloride formed against a standard solution of potassium dichromate(VI).

(a) (i) Write an equation for the reaction between iron and hydrochloric acid.

.....

(ii) Calculate the number of moles of hydrogen produced in the reaction.

.....

.....

.....

.....

(iii) Use your answers to parts (a)(i) and (ii) to determine the number of moles of iron and the mass of iron in the original sample. (If you have been unable to complete part (a)(ii) you should assume the answer to be 4.25×10^{-3} mol. This is not the correct answer.)

Moles of iron .....

Mass of iron .....

(iv) Calculate the percentage of iron in the original sample.

.....

.....

(7)

(b) (i) Write half-equations for the oxidation of Fe^{2+} and for the reduction of $Cr_2O_7^{2-}$ in acidic solution, and use these to construct an overall equation for the reaction between these two ions.

Half-equation for the oxidation of Fe^{2+}

.....

Half-equation for the reduction of $Cr_2O_7^{2-}$

.....

Overall equation

.....

(ii) The number of moles of iron in the sample was determined in part (a)(iii). Use this answer to calculate the volume of a 0.0200 mol dm^{-3} solution of potassium dichromate(VI) which would react exactly with the solution of iron(II) chloride formed in the reaction.

(If you have been unable to complete part (a)(iii) you should assume the answer to be 3.63×10^{-3} mol. This is not the correct answer.)

.....

.....

.....

.....

.....

(iii) Explain why an incorrect value for the number of moles of iron(II) chloride formed would have been obtained if the original solution had been titrated with potassium manganate(VII).

.....

.....

(7)

(Total 14 marks)

Q4. (a) State the origin of the colour of transition-metal complexes.

.....

.....

(2)

(b) Give **three** changes to a transition-metal complex which result in a change in colour.

Change 1 .....

Change 2 .....

Change 3 .....

.....

(3)

(c) You are provided with a 1.00 mol dm^{-3} solution of iron(III) ions and a visible-light spectrophotometer (colorimeter). Outline a plan for experiments using this solution and this apparatus which would enable you to determine the concentration of iron(III) ions in a solution of unknown concentration.

.....

.....

.....

.....

.....

.....

.....

.....

(5)
(Total 10 marks)

Q5. (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)

Q6. Which one of the following could **not** act as a ligand?

A F^-

B CH_3CH_3

C NH_2NH_2

D CH_3OCH_3

(Total 1 mark)

Q1.(a) Explain how the electron pair repulsion theory can be used to deduce the shape of, and the bond angle in, PF_3

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(6)

(b) State the full electron configuration of a cobalt(II) ion.

.....

(1)

(c) Suggest **one** reason why electron pair repulsion theory **cannot** be used to predict the shape of the $[CoCl_4]^{2-}$ ion.

.....

.....

(1)

(d) Predict the shape of, and the bond angle in, the complex rhodium ion $[RhCl_4]^{2-}$.

Shape .....

Bond angle .....

(2)
(Total 10 marks)

Q2. The pigment 'Cobalt Yellow' contains an octahedral complex of cobalt(III) and nitrate(III) ions (NO_2^-). Analysis shows that Cobalt Yellow contains 13.0% of cobalt, 18.6% of nitrogen and 25.9% of potassium by mass. The remainder is oxygen.

(a) Use these data to calculate the empirical formula of Cobalt Yellow. Show your working.

.....

.....

.....

.....

.....

.....

.....

(3)

(b) Deduce the structural formula of the cobalt-containing ion in Cobalt Yellow.

.....

(1)
(Total 4 marks)

Q3. Transition metals and their complexes have characteristic properties.

(a) Give the electron configuration of the Zn^{2+} ion.
Use your answer to explain why the Zn^{2+} ion is **not** classified as a transition metal ion.

Electron configuration .....

Explanation .....

.....

(2)

(b) In terms of bonding, explain the meaning of the term *complex*.

.....

.....

.....

.....

(2)

(c) Identify **one** species from the following list that does **not** act as a ligand. Explain your answer.

H_2 O^{2-} O_2 CO

Not a ligand.....

Explanation .....

(2)

(d) The element palladium is in the d block of the Periodic Table. Consider the following palladium compound which contains the sulfate ion.

$[Pd(NH_3)_4]SO_4$

(i) Give the oxidation state of palladium in this compound.

.....

(1)

(ii) Give the names of two possible shapes for the complex palladium ion in this compound.

Shape 1 .....

Shape 2 .....

(2)
(Total 9 marks)

Q4. Due to their electron arrangements, transition metals have characteristic properties including catalytic action and the formation of complexes with different shapes.

(a) Give **two other** characteristic properties of transition metals. For each property,illustrate your answer with a transition metal of your choice.

.....

.....

.....

.....

.....

.....

.....

.....

(4)

(b) Other than octahedral, there are several different shapes shown by transition metal complexes. Name **three** of these shapes and for each one give the formula of a complex with that shape.

.....

.....

.....

.....

.....

.....

.....

.....

.....

(6)

(c) It is possible for Group 2 metal ions to form complexes. For example, the $[Ca(H_2O)_6]^{2+}$ ion in hard water reacts with $EDTA^{4-}$ ions to form a complex ion in a similar manner to hydrated transition metal ions. This reaction can be used in a titration to measure the concentration of calcium ions in hard water.

(i) Write an equation for the equilibrium that is established when hydrated calcium ions react with $EDTA^{4-}$ ions.

.....

(1)

(ii) Explain why the equilibrium in part (c)(i) is displaced almost completely to the right to form the EDTA complex.

.....

.....

.....

.....

.....

.....

(3)

(iii) In a titration, 6.25 cm^3 of a 0.0532 mol dm^{-3} solution of EDTA reacted completely with the calcium ions in a 150 cm^3 sample of a saturated solution of calcium hydroxide.
Calculate the mass of calcium hydroxide that was dissolved in 1.00 dm^3 of the calcium hydroxide solution.

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

.....

(3)
(Total 17 marks)

Q5.(a) Explain the meaning of the terms *ligand* and *bidentate* as applied to transition metal complexes.

.....

.....

.....

.....

.....

.....

.....

.....

(2)

(b) Aqueous cobalt(II) ions react separately with an excess of chloride ions and with an excess of ammonia.

For each reaction, draw a diagram to illustrate the structure of, the shape of and the charge on the complex ion formed.

In each case, name the shape and indicate, on the diagram, a value for the ligand-metal-ligand bond angle.

(6)

(c) The complex ion formed in aqueous solution between cobalt(II) ions and chloride ions is a different colour from the $[Co(H_2O)_6]^{2+}$ ion.

Explain why these complex ions have different colours.

.....

.....

.....

.....

.....

.....

.....

.....

(3)

(d) In aqueous ammonia, cobalt(II) ions are oxidised to cobalt(III) ions by hydrogen peroxide. The H_2O_2 is reduced to hydroxide ions.

Calculate the minimum volume of 5.00 mol dm^{-3} H_2O_2 solution required to oxidise the Co^{2+} ions in 9.87 g of $CoSO_4.7H_2O$

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(5)
(Total 16 marks)

Q1.(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)

Q2. Transition elements form complex ions with a range of colours and shapes.

(a) By considering its electron arrangement, state how an element can be classified as a transition element.

.....

.....

(1)

(b) Explain the meaning of the term *complex ion*.

.....

.....

.....

(2)

(c) In terms of electrons, explain why an aqueous solution of cobalt(II) sulfate has a red colour.

.....

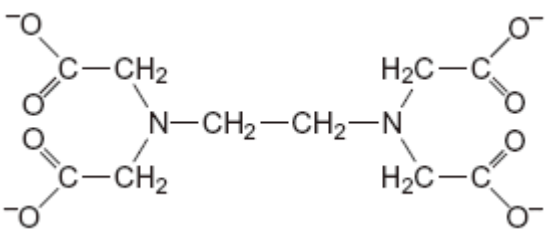
.....

.....

.....

(3)

(d) The ligand $EDTA^{4-}$ is shown below.



(i) Draw circles around the atoms of **two** different elements that link to a transition metal ion by a co-ordinate bond when $EDTA^{4-}$ behaves as a ligand.

(2)

(ii) Write an equation for the reaction between $EDTA^{4-}$ and a $[Co(H_2O)_6]^{2+}$ ion. Use the abbreviation $EDTA^{4-}$ in your equation.

.....

(1)

(iii) Explain why the complex ion, formed as a product of the reaction in part (d) (ii), is more stable than the $[Co(H_2O)_6]^{2+}$ ion.

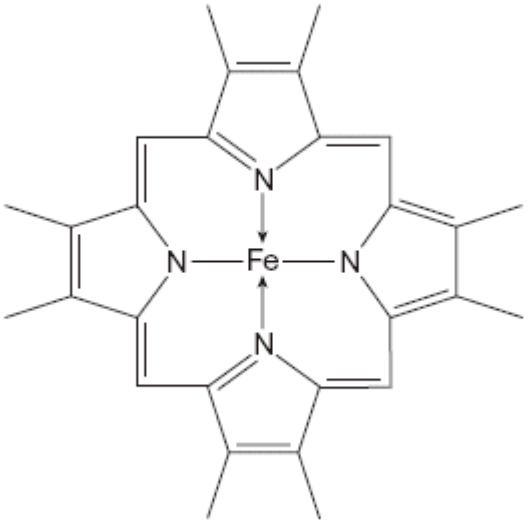
.....

.....

.....

(2)

(e) The diagram below shows part of the structure of haemoglobin.



Haemoglobin contains an iron(II) ion bonded to five nitrogen atoms and one other ligand. The fifth nitrogen atom and the additional ligand are not shown in this diagram.

(i) In this diagram, bonds between nitrogen and iron are shown as N→Fe and as N—Fe.

State the meaning of each of these symbols.

Meaning of → ……

Meaning of — ……

(2)

(ii) State the function of haemoglobin in the blood.

……

(1)

(iii) With reference to haemoglobin, explain why carbon monoxide is toxic.

……

……

……

(2)

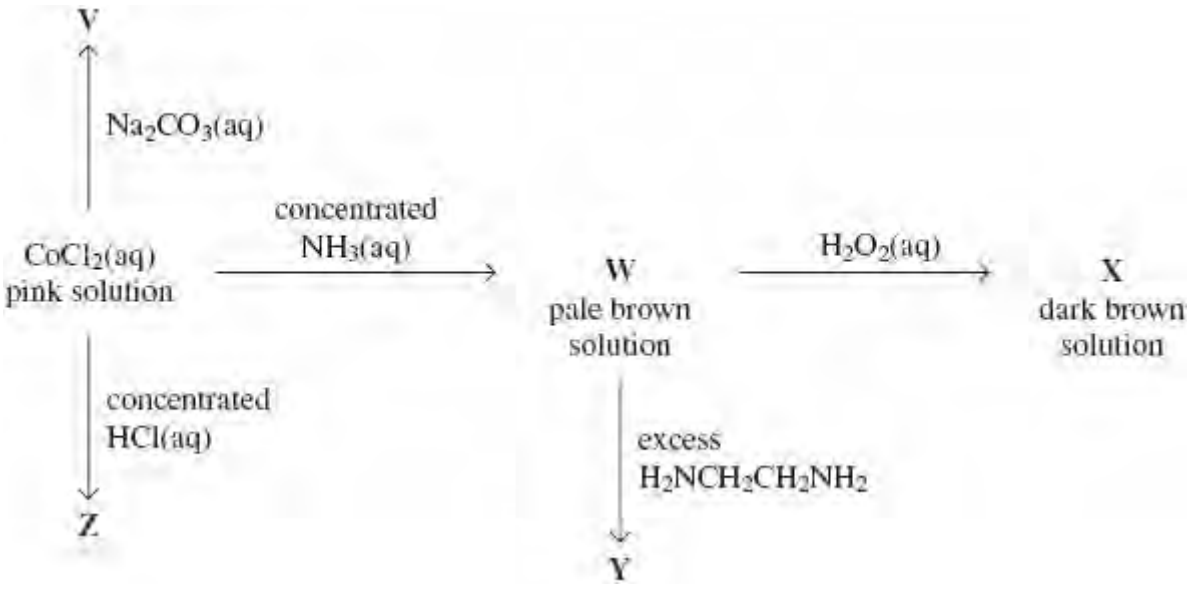
(Total 16 marks)

Q3. Transition metals form complex ions. Using actual examples of complex ions formed by transition metal ions, give the formula of

- a linear complex ion,
- a tetrahedral complex ion and
- an octahedral complex ion formed by using a bidentate ligand.

(Total 4 marks)

Q4. This question is about some reactions of cobalt compounds.



(a) Give the formula of the complex responsible for the pink colour in aqueous $CoCl_2$ and name its shape.

Formula .....

Name of shape .....

(2)

(b) Give the formula of the cobalt-containing compound **V** and describe its appearance.

Formula .....

Appearance .....

(2)

(c) Write an equation for the reaction that occurs when the pink solution is converted into **W**.

.....

(2)

(d) Give the formula of the cobalt-containing complex in **X** and state the role of the H_2O_2 in this reaction.

Formula .....

Role of H_2O_2 .....

(2)

(e) Give the formula of the cobalt-containing complex in **Y** and explain why this complex is more stable than the cobalt-containing complex in **W**.

Formula .....

Explanation .....

.....

.....

(3)

(f) Identify the cobalt-containing complex in solution **Z** and explain why its co-ordination number is different from that in the pink solution of $CoCl_2$

Complex .....

Explanation .....

.....

(2)
(Total 13 marks)

Q1. (a) The ion $C_2O_4^{2-}$ can act as a bidentate ligand.

(i) Explain the meaning of the term *bidentate ligand*.

.....

.....

(ii) Sketch the structure of the octahedral complex ion formed by Fe^{3+} ions which contains $C_2O_4^{2-}$ as the only ligand. Include the overall charge on the complex ion.

(5)

(b) Explain the meaning of the term *chelate effect*.

.....

.....

(2)

(c) The chloride ion can act as a monodentate ligand.

(i) Deduce the formula of the linear complex formed when an excess of concentrated hydrochloric acid is added to silver chloride.

.....

(ii) Explain why metal(II) ions do not usually form octahedral complexes when chloride ions are the only ligands.

.....

(2)

(d) The concentration of $C_2O_4^{2-}$ ions can be determined by titration in acidic solution using a standard solution of potassium manganate(VII). At room temperature, the reaction proceeds very slowly at first but becomes faster after some of the manganate(VII) ions have reacted.

(i) Suggest why this reaction is very slow at first.

.....

(ii) This is an example of an autocatalytic reaction. State the meaning of the term *autocatalytic* and identify the catalyst.

Meaning of the term autocatalytic .....

Catalyst .....

(iii) Suggest how this catalyst might be involved in the reaction.

.....

.....

.....

(5)
(Total 14 marks)

Q2. In the table below, which one of the following complex ions has a correct shape, co-ordination number and oxidation state?

	Complex	Shape	Co-ordination number	Oxidation state of central cation
A	$[Ag(CN)_2]^-$	Linear	2	–1

B	$[CuCl_4]^{2-}$	Tetrahedral	4	–2
C	$[Cr(C_2O_4)_3]^{3-}$	Octahedral	3	+3
D	$[Cu(NH_3)_4(H_2O)_2]^{2+}$	Octahedral	6	+2

(Total 1 mark)

Q3. (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)

Q4. (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)

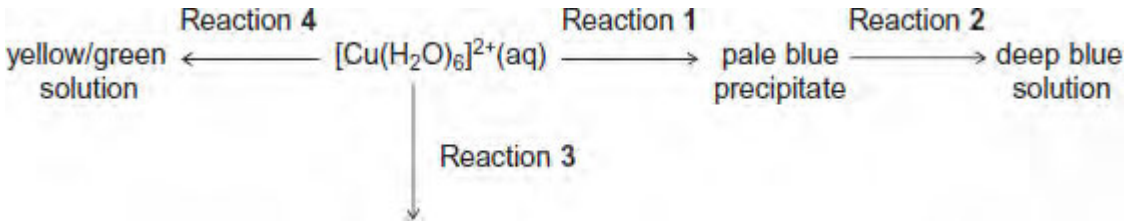
(f) Deduce the formula of the compound formed when ethane-1,2-diamine is treated with an excess of hydrochloric acid.

.....

(1)

(Total 11 marks)

Q1. 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)

Q2. This question explores some reactions and some uses of cobalt compounds.

(a) Ethanal is oxidised to ethanoic acid by oxygen. The equation for this reaction is

$2CH_3CHO + O_2 \longrightarrow 2CH_3COOH$

This redox reaction is slow at room temperature but speeds up in the presence of cobalt compounds.

Explain why a cobalt compound is able to act as a catalyst for this process.

Illustrate your explanation with **two** equations to suggest how, in the presence of water and hydrogen ions, Co^{3+} and then Co^{2+} ions could be involved in catalysing this reaction.

.....

.....

.....

.....

.....

.....

.....

.....

(4)

(b) In aqueous solution, the $[Co(H_2O)_6]^{2+}$ ion reacts with an excess of ethane-1,2-diamine to form the complex ion **Y**.

(i) Write an equation for this reaction.

Explain, in terms of the chelate effect, why the complex ion **Y** is formed in preference to the $[Co(H_2O)_6]^{2+}$ complex ion.

.....

.....

.....

.....

.....

.....

.....

(3)

(ii) Draw a diagram that shows the shape of the complex ion **Y** and shows the type of bond between the ethane-1,2-diamine molecules and the cobalt.

(3)

(c) Compound **Z** is a complex that contains only cobalt, nitrogen, hydrogen and chlorine.

A solid sample of **Z** was prepared by reaction of 50 cm^3 of 0.203 mol dm^{-3} aqueous cobalt(II) chloride with ammonia and an oxidising agent followed by hydrochloric acid.

When this sample of **Z** was reacted with an excess of silver nitrate, 4.22 g of silver chloride were obtained.

Use this information to calculate the mole ratio of chloride ions to cobalt ions in **Z**.

Give the formula of the complex cobalt compound **Z** that you would expect to be formed in the preparation described above.

Suggest **one** reason why the mole ratio of chloride ions to cobalt ions that you have calculated is different from the expected value.

.....

.....

.....

.....

.....

.....

.....

.....

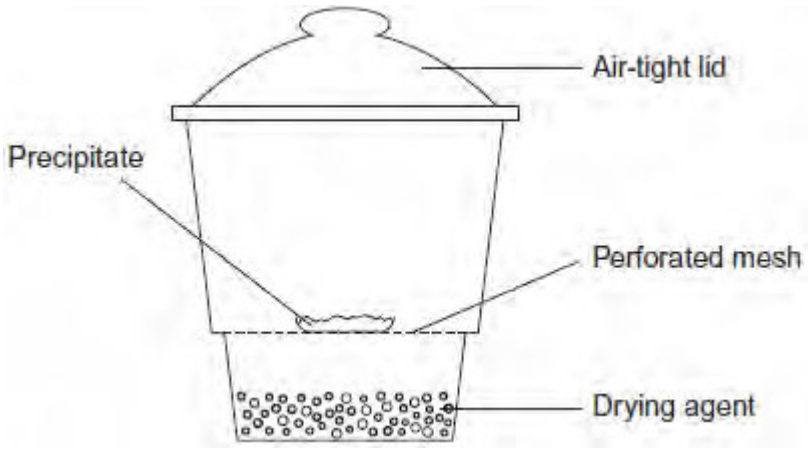
.....

.....

.....

(5)
(Total 15 marks)

Q3.A desiccator can be used to dry precipitates as shown in the diagram.



(a) Explain briefly how the precipitate in the desiccator becomes dry.

.....

.....

(1)

(b) Anhydrous cobalt(II) chloride is blue. It is often added to the drying agent to indicate the amount of moisture in the drying agent.

State the colour change of this cobalt compound that you would observe as the drying process takes place.

.....

(1)
(Total 2 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.

.....

.....

.....

.....

.....

.....

.....

.....

.....

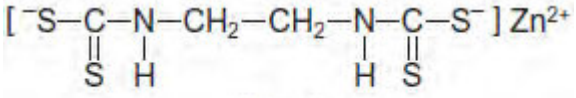
.....

.....

.....

(5)
(Total 17 marks)

Q5.(a) Because of the toxic nature of the copper(II) ion, a wide range of alternative anti-fungal drugs has been developed for use in agriculture. One example is Zineb.



Zineb

(i) The negative ion in Zineb could act as a bidentate ligand.

On the structure above, draw a ring around each of **two** atoms that could provide the lone pairs of electrons when this ion acts as a bidentate ligand.

(1)

(ii) Calculate the M_r of Zineb. Give your answer to the appropriate precision.

.....

.....

.....

.....

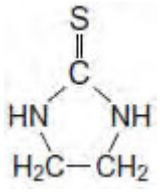
(1)

(iii) Name the functional group formed at each end of the negative ion when all the sulfur atoms in the structure of Zineb are replaced by oxygen atoms.

.....

(1)

(b) Zineb has been investigated for harmful effects. Generally, Zineb has been found to be safe to use in agriculture. It is only slightly soluble in water and is sprayed onto plants. A breakdown product of Zineb is ethylene thiourea (ETU), which is very soluble in water. The structure of ETU is shown below.



Determine the percentage, by mass, of sulfur in ETU (M_r = 102.1).

.....

.....

.....

(1)

(c) Chromatography is a technique used to show the presence of a small amount of ETU in Zineb.

Outline how this technique is used to separate and identify ETU from a sample of Zineb powder.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(4)
(Total 8 marks)

Q1. This question is about copper chemistry.

(a) Aqueous copper(II) ions $[Cu(H_2O)_6]^{2+}(aq)$ are blue.

(i) With reference to electrons, explain why aqueous copper(II) ions are blue.

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

.....

(3)

(ii) By reference to aqueous copper(II) ions, state the meaning of each of the **three** terms in the equation $\Delta E = hv$.

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

.....

(3)

(iii) Write an equation for the reaction, in aqueous solution, between $[Cu(H_2O)_6]^{2+}$ and an excess of chloride ions.

State the shape of the complex produced and explain why the shape differs from that of the $[Cu(H_2O)_6]^{2+}$ ion.

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

.....

(3)

(b) Draw the structure of the ethanedioate ion ($C_2O_4^{2-}$).
Explain how this ion is able to act as a ligand.

.....

.....

.....

.....

.....

(2)

(c) When a dilute aqueous solution containing ethanedioate ions is added to a solution containing aqueous copper(II) ions, a substitution reaction occurs. In this reaction four water molecules are replaced and a new complex is formed.

(i) Write an ionic equation for the reaction. Give the co-ordination number of the complex formed and name its shape.

.....

.....

.....

.....

.....

.....

(4)

(ii) In the complex formed, the two water molecules are opposite each other. Draw a diagram to show how the ethanedioate ions are bonded to a copper ion and give a value for one of the O–Cu–O bond angles. You are **not** required to show the water molecules.

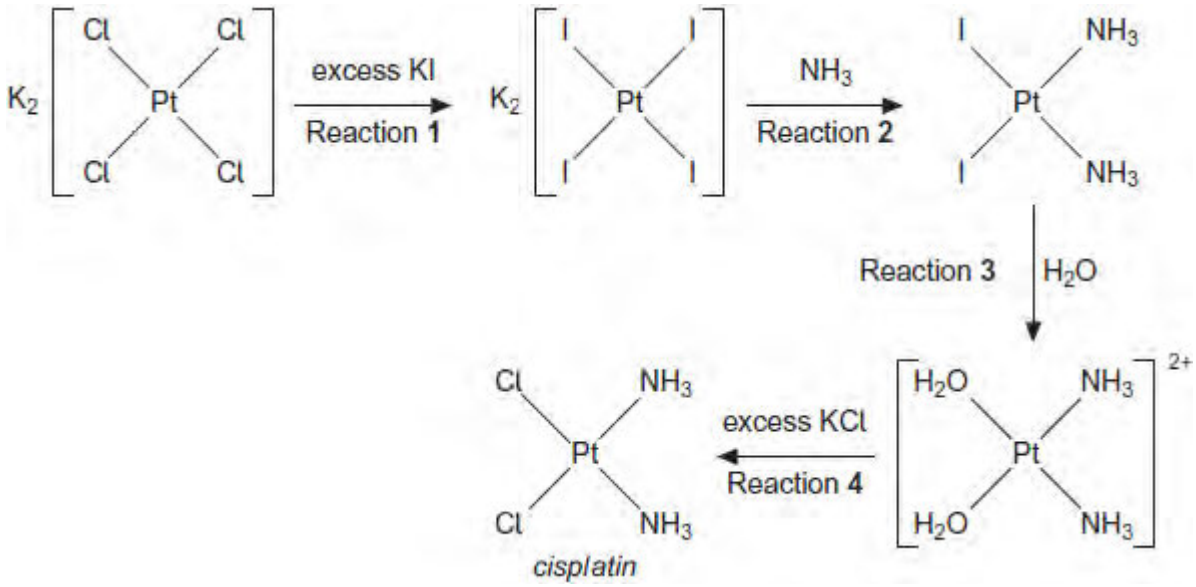
(2)
(Total 17 marks)

Q2. Complexes containing transition elements have a wide variety of uses including acting as dyestuffs like *Prussian Blue*.

Cisplatin is a platinum-based chemotherapy drug used to treat various types of cancers. It was the first member of a class of anti-cancer drugs that react with DNA in tumour cells.

Cisplatin is prepared from K_2PtCl_4 according to the following scheme.

All the reactions shown are reversible.



(a) Name the type of reaction occurring in all four steps of the scheme.

.....

(1)

(b) Explain why an excess of potassium iodide is used in Reaction **1**.

.....

.....

.....

(2)

(c) (i) Write an equation for Reaction **1**.

.....

.....

(1)

(ii) Calculate the percentage atom economy for the formation of K_2PtI_4 in Reaction **1**.
Show your working.

.....

.....

.....

.....

(2)

(d) In Reaction **3**, silver nitrate solution is added to improve the yield of product.

(i) Write the **simplest ionic** equation for the reaction of iodide ions with silver nitrate.

.....

(1)

(ii) Suggest why addition of silver nitrate improves the yield of product from Reaction **3**.

.....

.....

(1)

(e) Suggest two reasons, other than poor practical technique, why the overall yield of *cisplatin* in this synthesis may be low.

Reason 1 .....

.....

Reason 2 .....

.....

(2)

(f) The *cisplatin* formed in Reaction **4** is impure. Outline how the impure solid is purified by recrystallisation.

.....

.....

.....

.....

.....

(3)

(g) Platinum compounds are highly toxic.

(i) State why *cisplatin* is used in cancer treatment despite its toxicity.

.....

.....

(1)

(ii) Suggest a suitable precaution that should be taken by medical staff when using *cisplatin*.

.....

(1)

(Total 15 marks)

Q3.(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)

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. Which one of the following reactions in aqueous solution has the most positive change in entropy?

A $[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 4H_2O$

B $[Cu(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CuCl_4]^{2-} + 6H_2O$

C $[Cu(H_2O)_6]^{2+} + EDTA^{4-} \rightarrow [Cu(EDTA)]^{2-} + 6H_2O$

D $[Cu(H_2O)_6]^{2+} + 2H_2NCH_2CH_2NH_2 \rightarrow [Cu(H_2NCH_2CH_2NH_2)_2(H_2O)_2]^{2+} + 4H_2O$

(Total 1 mark)

Q3. Hydrogen peroxide is used as an oxidising agent in the preparation of transition metal complexes.

(a) Consider the following reaction scheme. All the complexes are in aqueous solution.

$$[Co(H_2O)_6]^{2+} \xrightarrow{\text{Reaction 1}} \text{cobalt(II) complex} \xrightarrow[H_2O_2]{\text{Reaction 2}} [Co(NH_3)_6]^{3+}$$

(i) Identify a reagent for Reaction **1** and describe the colour change that occurs.

.....

.....

.....

.....

(3)

(ii) State the colour of the final solution formed in Reaction **2**.

.....

(1)

(b) Consider the following reaction scheme. All the complexes are in aqueous solution.

$$[Cr(H_2O)_6]^{3+} \xrightarrow[\text{Excess NaOH(aq)}]{\text{Reaction 3}} \text{chromium(III) complex} \xrightarrow[H_2O_2]{\text{Reaction 4}} CrO_4^{2-}$$

(i) For Reaction **3**, state the colour of the initial and of the final solution and write an equation for the reaction.

.....

.....

.....

.....

(4)

(ii) Write a half-equation for the reduction of hydrogen peroxide to hydroxide ions.

Deduce an overall equation for Reaction **4** and state the colour of the final solution.

.....

.....

.....

.....

.....

.....

(4)

(c) The concentration of a hydrogen peroxide solution can be determined by titration with acidified potassium manganate(VII) solution. In this reaction the hydrogen peroxide is oxidised to oxygen gas.

A 5.00 cm^3 sample of the hydrogen peroxide solution was added to a volumetric flask and made up to 250 cm^3 of aqueous solution. A 25.0 cm^3 sample of this diluted solution was acidified and reacted completely with 24.35 cm^3 of 0.0187 mol dm^{-3} potassium manganate(VII) solution.

Write an equation for the reaction between acidified potassium manganate(VII) solution and hydrogen peroxide.
Use this equation and the results given to calculate a value for the concentration, in mol dm^{-3}, of the original hydrogen peroxide solution.
(If you have been unable to write an equation for this reaction you may assume that 3 mol of $KMnO_4$ react with 7mol of H_2O_2. This is **not** the correct reacting ratio.)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(5)
(Total 17 marks)

Q4. Ethanedioic acid is an important industrial chemical with a number of uses.

Ethanedioate ions, $C_2O_4^{2-}$, act as bidentate ligands with transition metal ions.

(a) Write an equation for the ligand substitution reaction of an excess of ethanedioate ions with aqueous cobalt(II) ions.

.....

(1)

(b) The table below shows some standard electrode potentials.

		$E^{\ominus}$ / V
$Fe^{3+}(aq) + e^-$	$\rightarrow Fe^{2+}(aq)$	+0.77
$2CO_2(g) + 2e^-$	$\rightarrow C_2O_4^{2-}(aq)$	–0.49

Use $E^{\ominus}$ values from the table to explain why an iron(III) complex is **not** formed when solutions containing ethanedioate ions and iron(III) ions are mixed.

.....

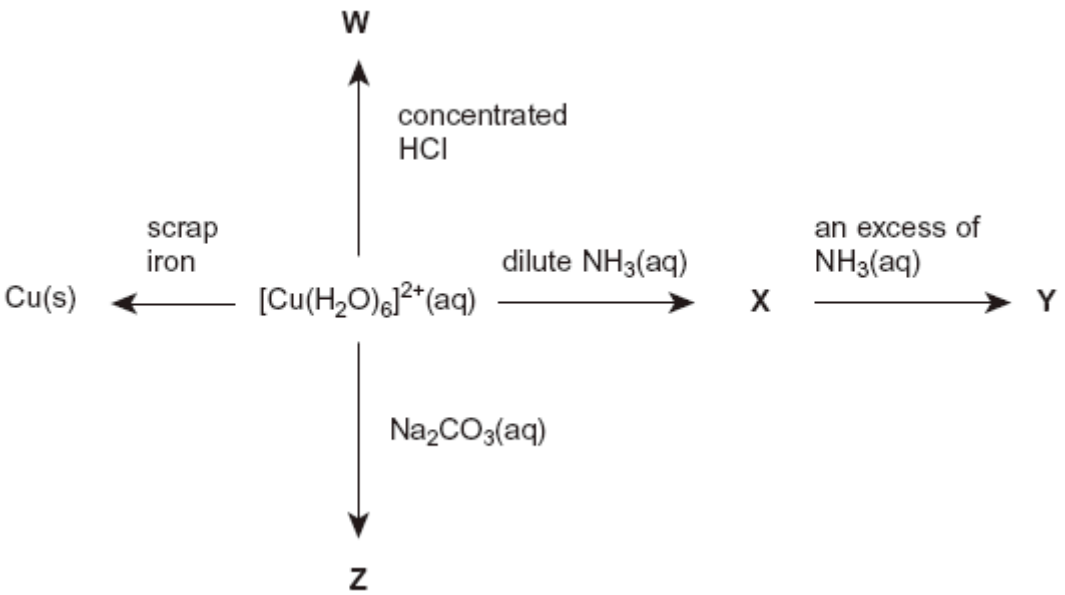
.....

.....

.....

(2)
(Total 3 marks)

Q5. The scheme below shows some reactions of copper(II) ions in aqueous solution. **W**, **X**, **Y** and **Z** are all copper-containing species.



(a) Identify ion **W**. Describe its appearance and write an equation for its formation from $[Cu(H_2O)_6]^{2+}(aq)$ ions.

Ion **W**.....

Appearance .....

Equation ….....

(3)

(b) Identify compound **X**. Describe its appearance and write an equation for its formation from $[Cu(H_2O)_6]^{2+}$(aq) ions.

Compound **X** .....

Appearance .....

Equation .....

(3)

(c) Identify ion **Y**. Describe its appearance and write an equation for its formation from **X**.

Ion **Y** .....

Appearance .....

Equation .....

(3)

(d) Identify compound **Z**. Describe its appearance and write an equation for its formation from $[Cu(H_2O)_6]^{2+}$(aq) ions.

Compound **Z** .....

Appearance .....

Equation .....

(3)

(e) Copper metal can be extracted from a dilute aqueous solution containing copper(II) ions using scrap iron.

(i) Write an equation for this reaction and give the colours of the initial and final aqueous solutions.

Equation .....

Initial colour .....

Final colour .....

(3)

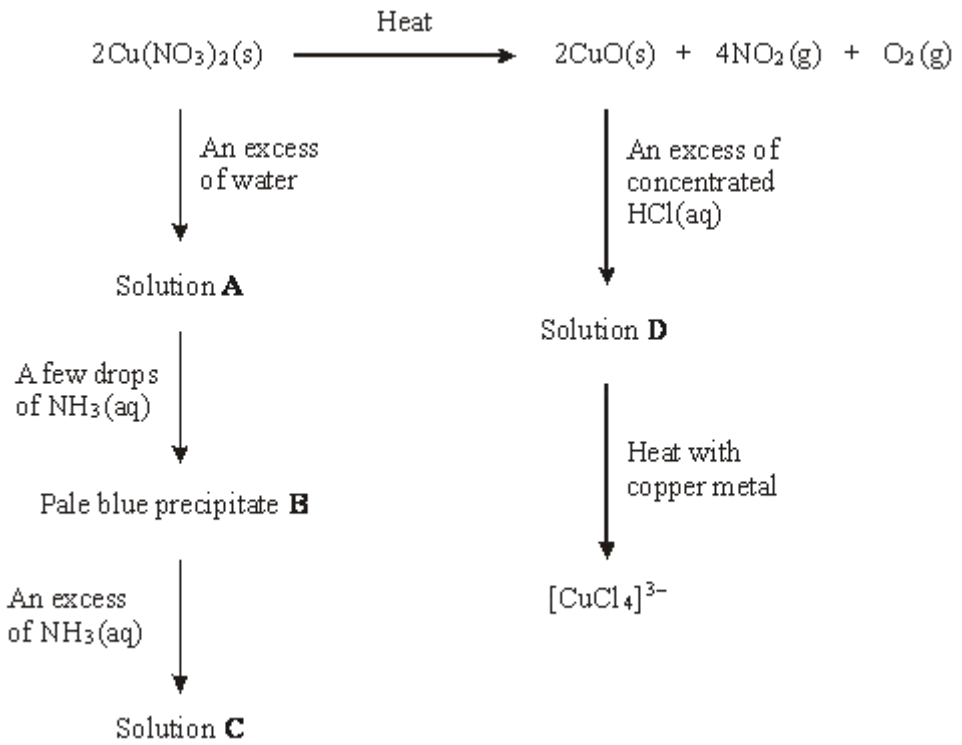
(ii) This method of copper extraction uses scrap iron. Give **two** other reasons why this method of copper extraction is more environmentally friendly than reduction of copper oxide by carbon.

Reason 1 .....

Reason 2 .....

(2)
(Total 17 marks)

Q1. 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)

Q2. (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)

Q3. (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)

Q4. (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)

Q1. (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)

Q2. Which one of the following statements about the reaction below is **false**?

$$[Cu(H_2O)_6]^{2+} + EDTA^{4-} \rightleftharpoons [Cu(EDTA)]^{2-} + 6H_2O$$

A $[Cu(EDTA)]^{2-}$ is a more stable complex than $[Cu(H_2O)_6]^{2+}$

B Both $[Cu(H_2O)_6]^{2+}$ and $[Cu(EDTA)]^{2-}$ are octahedral complexes.

C There is an increase in entropy when the reaction occurs.

D There is a redox reaction.

(Total 1 mark)

Q3. Which one of the following statements is true?

A A blue solution containing the ion $[CoCl_4]^{2-}$ turns pink when added to an excess of water.

B A purple solution is formed when chlorine is bubbled into aqueous sodium bromide.

C A yellow precipitate is formed when aqueous silver nitrate is added to aqueous sodium chloride.

D A green solution containing the ion $[CuCl_4]^{2-}$ turns blue when added to an excess of concentrated hydrochloric acid.

(Total 1 mark)

Q1. Which one of the following reactions in aqueous solution has the most positive change in entropy?

A $[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+} + 4H_2O$

B $[Cu(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CuCl_4]^{2-} + 6H_2O$

C $[Cu(H_2O)_6]^{2+} + EDTA^{4-} \rightarrow [Cu(EDTA)]^{2-} + 6H_2O$

D $[Cu(H_2O)_6]^{2+} + 2H_2NCH_2CH_2NH_2 \rightarrow [Cu(H_2NCH_2CH_2NH_2)_2(H_2O)_2]^{2+} + 4H_2O$

(Total 1 mark)

Q2. In which one of the following reactions is a heterogeneous catalyst **not** used?

A $N_2 + 3H_2 \rightarrow 2NH_3$

B $CO + NO \rightarrow CO_2 + \frac{1}{2}N_2$

C $CO_2 + C \rightarrow 2CO$

D $SO_2 + \frac{1}{2}O_2 \rightarrow SO_3$

(Total 1 mark)

Q3. A 0.0720 g sample of reducing agent **R** was dissolved in water and acidified with an excess of dilute H_2SO_4. The resulting solution was found to react with exactly 18.0 cm^3 of a 0.0200 mol dm^{-3} solution of $KMnO_4$.

In this reaction, 5 mol of **R** react with 3 mol of $KMnO_4$. The M_r of **R** is

A 120

B 167

C 240

D 333

(Total 1 mark)

Q4. The vanadium does **not** have an oxidation state of +3 in

A $[V(H_2O)_6]^{3+}$

B $[V(C_2O_4)_3]^{3-}$

C $[V(OH)_3(H_2O)_3]$

D $[VCl_4]^{3-}$

(Total 1 mark)

Q5. Use your knowledge of the chemistry of transition metals to predict which of the following will convert $[Mn(H_2O)_6]^{2+}$ into MnO_4^{2-}

A an acid and a reducing agent

B an acid and an oxidising agent

C an alkali and a reducing agent

D an alkali and an oxidising agent

(Total 1 mark)

Q6. Which one of the following could **not** act as a ligand?

A F^-

B CH_3CH_3

C NH_2NH_2

D CH_3OCH_3

(Total 1 mark)

Q7. In the table below, which one of the following complex ions has a correct shape, co-ordination number and oxidation state?

	Complex	Shape	Co-ordination number	Oxidation state of central cation
A	$[Ag(CN)_2]^-$	Linear	2	–1
B	$[CuCl_4]^{2-}$	Tetrahedral	4	–2
C	$[Cr(C_2O_4)_3]^{3-}$	Octahedral	3	+3
D	$[Cu(NH_3)_4(H_2O)_2]^{2+}$	Octahedral	6	+2

(Total 1 mark)

Q8. Which one of the following would **not** reduce an acidified aqueous solution of potassium dichromate(VI)?

A CH_3COOH

B Zn

C CH_3CHO

D $Fe^{2+}(aq)$

(Total 1 mark)

Q9. Which one of the following would **not** react with aqueous silver nitrate to produce a precipitate that is soluble in concentrated aqueous ammonia?

A $CaBr_2$

B $[COCl_4]^{2-}$

C $(CH_3)_4N^+I^-$

D CH_3COCl

(Total 1 mark)

Q10. Which one of the following statements about the reaction below is **false**?

$$[Cu(H_2O)_6]^{2+} + EDTA^{4-} \rightleftharpoons [Cu(EDTA)]^{2-} + 6H_2O$$

A $[Cu(EDTA)]^{2-}$ is a more stable complex than $[Cu(H_2O)_6]^{2+}$

B Both $[Cu(H_2O)_6]^{2+}$ and $[Cu(EDTA)]^{2-}$ are octahedral complexes.

C There is an increase in entropy when the reaction occurs.

D There is a redox reaction.

(Total 1 mark)

Q11. Which one of the following can act as an oxidising agent but not as a reducing agent?

A CH_3CHO

B Fe^{2+}

C I^-

D MnO_4^-

(Total 1 mark)

Q12. Aqueous $C_2O_4^{2-}$ ions react with MnO_4^- ions in acidic solution according to the equation

$$5\ C_2O_4^{2-} + 2MnO_4^- + 16H^+ \rightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$$

Under the same conditions Fe^{2+} ions also react with MnO_4^- ions. How many moles of MnO_4^- ions are required to react exactly with one mole of $Fe(C_2O_4).2H_2O$?

A 0.4

B 0.6

C 2.5

D 7.5

(Total 1 mark)

Q13. The percentage of iron in a sample of impure iron(II) sulphate crystals can be determined by titrating solutions, made from separate weighed samples acidified with dilute sulphuric acid, against a standard solution of potassium manganate(VII).

Which one of the following statements explains why dilute hydrochloric acid is unsuitable for use in this titration?

A HCl will oxidise Fe^{2+} to Fe^{3+}

B Cl^- will reduce Fe^{3+} to Fe^{2+}

C Cl^- will reduce MnO_4^-

D HCl is a strong acid

(Total 1 mark)

Q14. The percentage of iron in a sample of impure iron(II) sulphate crystals can be determined by titrating solutions, made from separate weighed samples acidified with dilute sulphuric acid, against a standard solution of potassium manganate(VII).

Which one of the following would lead to an inaccurate result?

A transferring the weighed sample of iron(II) sulphate into a wet conical flask

B failing to measure accurately the volume of water used to dissolve each weighed sample of iron(II) sulphate

C transferring the standard solution of potassium manganate(VII) from its original container to the burette using a wet beaker

D failing to measure accurately the volume of dilute sulphuric acid added to the mixture before titration

(Total 1 mark)

Q15. The percentage of iron in a sample of impure iron(II) sulphate crystals can be determined by titrating solutions, made from separate weighed samples acidified with dilute sulphuric acid, against a standard solution of potassium manganate(VII).

Which one of the following would lead to the greatest error in the calculation of the percentage of iron(II) in the sample?

A an error of 0.005 g made when weighing out a sample of mass 0.987 g

B an end-point error of 0.1 cm^3 in 25.0 cm^3

C an error of 5 cm^3 when measuring out 25.0 cm^3 of dilute sulphuric acid

D using the average of the titration values 25.4, 25.7 and 25.9 when the correct value is 25.5 cm^3

(Total 1 mark)

Q16. Which of the species given below can behave as ligands?

NH_2^- NH_3 NH_4^+

A all three

B only NH_3

C NH_3 and NH_4^+

D NH_2^- and NH_3

(Total 1 mark)

Q17. Which one of the following statements is true?

A A blue solution containing the ion $[CoCl_4]^{2-}$ turns pink when added to an excess of water.

B A purple solution is formed when chlorine is bubbled into aqueous sodium bromide.

C A yellow precipitate is formed when aqueous silver nitrate is added to aqueous sodium chloride.

D A green solution containing the ion $[CuCl_4]^{2-}$ turns blue when added to an excess of concentrated hydrochloric acid.

(Total 1 mark)

Q18. In which one of the following reactions does the metal species undergo reduction?

A $MnO_2 + 4HCl \rightarrow MnCl_2 + 2H_2O + Cl_2$

B $[Cu(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CuCl_4]^{2-} + 6H_2O$

C $CrO_7^{2-} + 2OH^- \rightarrow 2CrO_4^{2-} + H_2O$

D $TiO_2 + 2C + 2Cl_2 \rightarrow TiCl_4 + 2CO$

(Total 1 mark)

Q19. When vanadium reacts with chlorine at 400°C, a brown compound is obtained. When an aqueous solution containing 0.193 g of this compound was treated with aqueous silver nitrate all the chlorine in the compound was precipitated as silver chloride. The mass of silver chloride (AgCl) produced was 0.574 g. Which one of the following could be the formula of the brown compound?

A VCl

B VCl_2

C VCl_3

D VCl_4

(Total 1 mark)

Q20. The oxidation of ethanedioate (*oxalate*) ions by manganate(VII) ions can be represented by the half equations:

$$C_2O_4^{2-}(aq) \rightarrow 2CO_2(g) + 2e^-$$

$$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightarrow Mn^{2+}(aq) + 4H_2O(l)$$

What volume (in cm^3) of 0.02 M $KMnO_4$ is required to oxidise completely a solution containing 0.02 mol of ethanedioate ions?

A 25

B 40

C 250

D 400

(Total 1 mark)

Q21. Which one of the following electronic configurations is that of a transition element?

A [Ar] $4s^2 3d^{10}$

B [Ar] $4s^2 3d^9$

C [A] $4s^2 3d^0$

D [Ar] $4s^2 3d^{10} 4p^1$

(Total 1 mark)

Q1. 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)

Q2. Transition metal compounds have a range of applications as catalysts.

(a) State the general property of transition metals that allows the vanadium in vanadium(V) oxide to act as a catalyst in the Contact Process.

.....

(1)

(b) Write **two** equations to show how vanadium(V) oxide acts as a catalyst in the Contact Process.

Equation 1

.....

Equation 2

.....

(2)

(c) In the Contact Process, vanadium(V) oxide acts as a heterogeneous catalyst.

(i) Give the meaning of the term *heterogeneous*.

.....

.....

.....

(1)

(ii) Give **one** reason why impurities in the reactants can cause problems in processes that use heterogeneous catalysts.

.....

.....

.....

(1)

(d) The oxidation of $C_2O_4^{2-}$ ions by MnO_4^- ions in acidic solution is an example of a reaction that is autocatalysed.

(i) Give the meaning of the term *autocatalysed*.

.....

.....

.....

(1)

(ii) Identify the autocatalyst in this reaction.

.....

(1)

(iii) Write **two** equations to show how the autocatalyst is involved in this oxidation of $C_2O_4^{2-}$ ions.

Equation 1

.....

Equation 2

.....

(2)
(Total 9 marks)

Q3. This question explores some reactions and some uses of cobalt compounds.

(a) Ethanal is oxidised to ethanoic acid by oxygen. The equation for this reaction is

$2CH_3CHO + O_2 \longrightarrow 2CH_3COOH$

This redox reaction is slow at room temperature but speeds up in the presence of cobalt compounds.

Explain why a cobalt compound is able to act as a catalyst for this process.

Illustrate your explanation with **two** equations to suggest how, in the presence of water and hydrogen ions, Co^{3+} and then Co^{2+} ions could be involved in catalysing this reaction.

.....

.....

.....

.....

.....

.....

.....

.....

(4)

(b) In aqueous solution, the $[Co(H_2O)_6]^{2+}$ ion reacts with an excess of ethane-1,2-diamine to form the complex ion **Y**.

(i) Write an equation for this reaction.

Explain, in terms of the chelate effect, why the complex ion **Y** is formed in preference to the $[Co(H_2O)_6]^{2+}$ complex ion.

.....

.....

.....

.....

.....

.....

.....

(3)

(ii) Draw a diagram that shows the shape of the complex ion **Y** and shows the type of bond between the ethane-1,2-diamine molecules and the cobalt.

(3)

(c) Compound **Z** is a complex that contains only cobalt, nitrogen, hydrogen and chlorine.

A solid sample of **Z** was prepared by reaction of 50 cm^3 of 0.203 mol dm^{-3} aqueous cobalt(II) chloride with ammonia and an oxidising agent followed by hydrochloric acid.

When this sample of **Z** was reacted with an excess of silver nitrate, 4.22 g of silver chloride were obtained.

Use this information to calculate the mole ratio of chloride ions to cobalt ions in **Z**.

Give the formula of the complex cobalt compound **Z** that you would expect to be formed in the preparation described above.

Suggest **one** reason why the mole ratio of chloride ions to cobalt ions that you have calculated is different from the expected value.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(5)
(Total 15 marks)

Q4. The table below shows some successive ionisation energy data for atoms of three different elements **X**, **Y** and **Z**.

Elements **X**, **Y** and **Z** are Ca, Sc and V but not in that order.

	First	**Second**	**Third**	**Fourth**	**Fifth**	**Sixth**
X	648	1370	2870	4600	6280	12 400
Y	590	1150	4940	6480	8120	10 496
Z	632	1240	2390	7110	8870	10 720

(a) Which element is calcium?

X ⬭

Y ⬭

Z ⬭

(1)

(b) Which element is vanadium?

X ⬭

Y ⬭

Z ⬭

(1)

(c) Justify your choice of vanadium in part (b)

.....

.....

.....

(1)

(d) An acidified solution of NH_4VO_3 reacts with zinc.

Explain how observations from this reaction show that vanadium exists in at least two different oxidation states.

.....

.....

.....

.....

.....

(2)

(e) The vanadium in 50.0 cm^3 of a 0.800 mol dm^{-3} solution of NH_4VO_3 reacts with 506 cm^3 of sulfur(IV) oxide gas measured at 20.0 °C and 98.0 kPa.

Use this information to calculate the oxidation state of the vanadium in the solution after the reduction reaction with sulfur(IV) oxide.
Explain your working.
The gas constant R = 8.31 J K^{-1} mol^{-1}.

Oxidation state = ...

(6)
(Total 11 marks)

Q5. When iodine molecules are dissolved in aqueous solutions containing iodide ions, they react to form triiodide ions (I_3^-).

$$I_2 + I^- \longrightarrow I_3^-$$

The reaction above between I^- ions and $S_2O_8^{2-}$ ions has a high activation energy and $S_2O_8^{2-}$ ions are only reduced slowly to SO_4^{2-} ions.
The reaction is catalysed by Fe^{2+} ions.

(a) Explain why the reaction between I^- ions and $S_2O_8^{2-}$ ions is slow.

.....

.....

.....

(1)

(b) Other than having variable oxidation states, explain why Fe^{2+} ions are good catalysts for this reaction.

.....

.....

.....

(1)

(c) Write a half-equation for the reduction of $S_2O_8^{2-}$ ions to SO_4^{2-} ions.

.....

.....

(1)

(d) Construct an overall equation for the reaction between $S_2O_8^{2-}$ ions and I^- ions.

.....

.....

.....

.....

(1)
(Total 4 marks)

Q6. A student carried out an experiment to find the mass of $FeSO_4.7H_2O$ in an impure sample, **X**.
The student recorded the mass of **X**. This sample was dissolved in water and made up to 250 cm^3 of solution.
The student found that, after an excess of acid had been added, 25.0 cm^3 of this solution reacted with 21.3 cm^3 of a 0.0150 mol dm^{-3} solution of $K_2Cr_2O_7$

(a) Use this information to calculate a value for the mass of $FeSO_4.7H_2O$ in the sample of **X**.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(5)

(b) The student found that the calculated mass of $FeSO_4.7H_2O$ was greater than the actual mass of the sample that had been weighed out. The student realised that this could be due to the nature of the impurity.

Suggest **one** property of an impurity that would cause the calculated mass of $FeSO_4.7H_2O$ in **X** to be greater than the actual mass of **X**.
Explain your answer.

.....

.....

.....

.....

(2)
(Total 7 marks)

Q1. Iron(II) ethanedioate is another insoluble solid used as a pigment in paints and glass. It occurs as a dihydrate ($FeC_2O_4.2H_2O$). One procedure used for the preparation of iron(II) ethanedioate is outlined below.

Procedure

A 6.95 g sample of hydrated iron(II) sulfate ($FeSO_4.7H_2O$) was added to 100 cm^3 of water in a beaker and stirred until all of the solid dissolved. A 150 cm^3 volume of 0.20 mol dm^{-3} sodium ethanedioate solution was added to the beaker. The mixture was stirred until precipitation was complete. After filtration, 3.31 g of the dihydrate ($FeC_2O_4.2H_2O$) were collected.

(a) Write an equation for the reaction between iron(II) sulfate and sodium ethanedioate.

.....

(1)

(b) Calculate the amount, in moles, of $FeSO_4.7H_2O$ in 6.95 g of hydrated iron(II) sulfate. Show your working.

.....

.....

.....

(2)

(c) Calculate the amount, in moles, of sodium ethanedioate in 150 cm^3 of 0.20 mol dm^{-3} sodium ethanedioate solution.

.....

.....

(1)

(d) Calculate the percentage yield of iron(II) ethanedioate dihydrate (M_r = 179.8) formed in this reaction.
Give your answer to the appropriate precision. Show your working.

.....

.....

.....

.....

(2)

(e) In this experiment, no side reactions take place, the reagents are pure and the reaction goes to completion.

Suggest **one** reason why the yield of iron(II) ethanedioate dihydrate in this experiment is less than 100%.

.....

.....

.....

(1)

(f) When dissolved in dilute sulfuric acid, the number of moles of ethanedioate ions in a pigment can be determined by titration with acidified potassium manganate(VII).

Explain why the titration of a sample of iron(II) ethanedioate would require a different amount of potassium manganate(VII) than a titration of an equimolar amount of copper(II) ethanedioate.

.....

.....

.....

.....

(2)
(Total 9 marks)

Q2.(a) Explain the meaning of the terms *ligand* and *bidentate* as applied to transition metal complexes.

.....

.....

.....

.....

.....

.....

.....

.....

(2)

(b) Aqueous cobalt(II) ions react separately with an excess of chloride ions and with an excess of ammonia.

For each reaction, draw a diagram to illustrate the structure of, the shape of and the charge on the complex ion formed.

In each case, name the shape and indicate, on the diagram, a value for the ligand-metal-ligand bond angle.

(6)

(c) The complex ion formed in aqueous solution between cobalt(II) ions and chloride ions is a different colour from the $[Co(H_2O)_6]^{2+}$ ion.

Explain why these complex ions have different colours.

.....

.....

.....

.....

.....

.....

.....

.....

(3)

(d) In aqueous ammonia, cobalt(II) ions are oxidised to cobalt(III) ions by hydrogen peroxide. The H_2O_2 is reduced to hydroxide ions.

Calculate the minimum volume of 5.00 mol dm^{-3} H_2O_2 solution required to oxidise the

Co^{2+} ions in 9.87 g of $CoSO_4.7H_2O$

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(5)
(Total 16 marks)

Q3. You may find the following electrode potential data helpful when answering this question.

Electrode half-equation	$E^{\ominus}$ / V
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \longrightarrow 2Cr^{3+}(aq) + 7H_2O(l)$	+1.33
$O_2(g) + 4H^+(aq) + 4e^- \longrightarrow 2H_2O(l)$	+1.23
$Cr^{3+}(aq) + e^- \longrightarrow Cr^{2+}(aq)$	–0.44
$Zn^{2+}(aq) + 2e^- \longrightarrow Zn(s)$	–0.76
$Cr^{2+}(aq) + 2e^- \longrightarrow Cr(s)$	–0.91

(a) Describe the colour changes that you would observe when an excess of zinc is added to an acidified solution of potassium dichromate(VI) in the absence of air.

For each colour change, identify the coloured ions responsible and write an equation for each reaction that occurs with zinc.
In the equations, you should represent the ions in their simplest form, for example Cr^{3+}.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

(5)

(b) Describe what you would observe when dilute aqueous sodium hydroxide is added, dropwise until in excess, to a dilute aqueous solution containing chromium(III) ions.

Write **two** equations to illustrate your observations.
In these equations you should give the full formula of each of the complexes, for example $[Cr(H_2O)_6]^{3+}$.

.....

.....

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

.....

(4)

(c) When an aqueous solution containing $[Cr(H_2O)_6]^{3+}$ ions is warmed in the presence of Cl^- ions, $[Cr(H_2O)_5Cl]^{2+}$ ions are formed and the colour of the solution changes.

Name this type of reaction.

Suggest, in terms of electrons, why the colours of the complex ions are different.

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

(3)

(d) The chromium(II) ion $[Cr(H_2O)_6]^{2+}$ has different properties from the $[Cr(H_2O)_6]^{3+}$ ion.

Use data from the table above to explain why, in an open container, $[Cr(H_2O)_6]^{2+}$(aq) ions change into $[Cr(H_2O)_6]^{3+}$(aq) ions.

Suggest the identity of the products formed in each case when sodium carbonate solution is added to separate solutions containing $[Cr(H_2O)_6]^{2+}$(aq) ions and $[Cr(H_2O)_6]^{3+}$(aq) ions.

Explain why the $[Cr(H_2O)_6]^{3+}$(aq) ions behave differently from the $[Cr(H_2O)_6]^{2+}$(aq) ions.

In your answer to this part of the question, equations are **not** required.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Extra space) .....

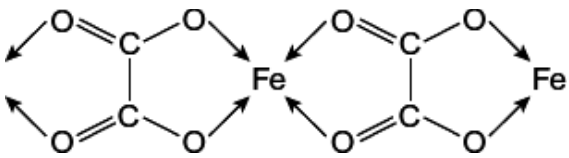
.....

.....

.....

(7)
(Total 19 marks)

Q4. Solid iron(II) ethanedioate dihydrate ($FeC_2O_4.2H_2O$) has a polymeric structure.
Two repeating units in the polymer chain are shown.



Each iron ion is also bonded to two water molecules. These are **not** shown in the diagram.

(a) Name the type of bond that is represented by the arrows.

.....

(1)

(b) In terms of electrons explain how the water molecules, **not** shown in the diagram, form bonds to the iron.

.....

.....

.....

.....

(2)

(c) Predict the value of the bond angle between the two bonds to iron that are formed by these two water molecules.

.....

(1)

(d) Iron(II) ethanedioate dihydrate can be analysed by titration using potassium manganate(VII) in acidic solution. In this reaction, manganate(VII) ions oxidise iron(II) ions and ethanedioate ions.

A 1.381 g sample of impure $FeC_2O_4.2H_2O$ was dissolved in an excess of dilute sulfuric acid and made up to 250 cm^3 of solution.
25.0 cm^3 of this solution decolourised 22.35 cm^3 of a 0.0193 mol dm^{-3} solution of potassium manganate(VII).

(i) Use the half-equations given below to calculate the reacting ratio of moles of manganate(VII) ions to moles of iron(II) ethanedioate.

$$MnO_4^- + 8H^+ + 5e^- \longrightarrow Mn^{2+} + 4H_2O$$

$$Fe^{2+} \longrightarrow Fe^{3+} + e^-$$

$$C_2O_4^{2-} \longrightarrow 2CO_2 + 2e^-$$

.....

.....

.....

(1)

(ii) Calculate the percentage by mass of $FeC_2O_4.2H_2O$ in the original sample.

(If you have been unable to answer part (d)(i) you may assume that three moles of manganate(VII) ions react with seven moles of iron(II) ethanedioate. This is **not** the correct ratio.)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(5)
(Total 10 marks)

Q1. An experiment was carried out to determine the original concentration of iron(II) ions in a solution that had been stored in air. An excess of zinc and acid was added to this solution. The mixture was then filtered to remove the excess zinc before titration.

(a) Suggest why the zinc and acid were added.

.....

.....

(1)

(b) Explain why it was necessary to remove the excess zinc.

.....

.....

(1)
(Total 2 marks)

Q2. (a) The iron(II) ions in well-water can be removed by oxidation using potassium manganate(VII) in **alkaline** solution. A mixture containing solid iron(III) hydroxide and solid manganese(IV) oxide is formed. These solid products can be removed by filtration under reduced pressure.

(i) Draw a diagram of the apparatus used for this filtration. Do **not** include the apparatus used to reduce the pressure.

(2)

(ii) An equation representing the oxidation reaction is given below.

$$3Fe^{2+}(aq) + KMnO_4(aq) + 5OH^-(aq) + 2H_2O(l) \longrightarrow 3Fe(OH)_3(s) + MnO_2(s) + K^+(aq)$$

Calculate the mass, in grams, of $KMnO_4$ required to react with the iron(II) ions in 1.00 dm^3 of well-water that has an iron(II) concentration of 0.225 mol dm^{-3}.
Give your answer to the appropriate precision.
Show your working.

.....

.....

.....

.....

.....

.....

(3)

(iii) In practice, a slight excess of potassium manganate(VII) is used to treat the well-water.
Although this treated water is safe to drink, this excess of potassium manganate(VII) is undesirable. Suggest **one** reason, other than colour, why the excess is undesirable.

.....

.....

(1)

(b) Suggest **one** reason why the colour of potassium manganate(VII) solution can be a source of error when using a volumetric (graduated) flask to prepare a standard solution.

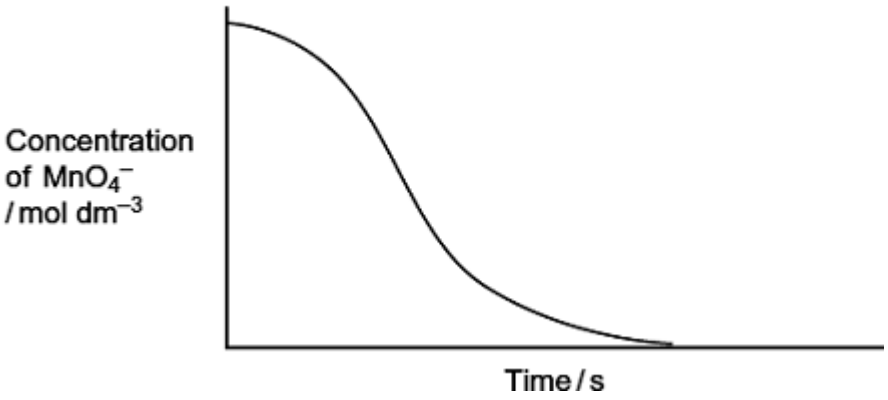
.....

.....

(1)
(Total 7 marks)

Q3. An acidified solution of potassium manganate(VII) was reacted with a sample of sodium ethanedioate at a constant temperature of 60 °C. The concentration of the manganate(VII) ions in the reaction mixture was determined at different times using a spectrometer to measure the light absorbed.

The following results were obtained.



(a) Write an equation for the reaction between manganate(VII) ions and ethanedioate ions in acidic solution.

.....

.....

.....

(Extra space) .....

.....

(2)

(b) By considering the properties of the reactants and products, state why it is possible to use a spectrometer to measure the concentration of the manganate(VII) ions in this reaction mixture.

.....

.....

.....

.....

(2)

(c) This reaction is autocatalysed. Give the meaning of the term *autocatalyst*. Explain how the above curve indicates clearly that the reaction is autocatalysed.

Meaning of *autocatalyst* .....

.....

Explanation .....

.....

.....

.....

(3)

(d) Identify the autocatalyst in this reaction.

.....

(1)

(e) Write **two** equations to show how the autocatalyst is involved in this reaction.

Equation 1 .....

Equation 2 .....

(2)
(Total 10 marks)

Q4. When using potassium manganate(VII) in redox titrations with iron(II) ions it is essential that the reaction mixture is acidified. Normally, dilute sulfuric acid is used.

(a) State why an excess of hydrogen ions is added to the reaction mixture.

.....

.....

(1)

(b) State why the acid used must **not** be ethanoic acid.

.....

.....

(1)

(c) Explain why an indicator is **not** needed in this redox titration.

.....

.....

(1)
(Total 3 marks)

Q5.(a) Use data from the table below to explain why dilute hydrochloric acid cannot be used to acidify potassium manganate(VII) in a titration.

	$E^{\ominus}$ / V
$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightarrow Mn^{2+}(aq) + 4H_2O(l)$	+1.51
$Cl_2(aq) + 2e^- \rightarrow 2Cl^-(aq)$	+1.36
$2H^+(aq) + 2e^- \rightarrow H_2(aq)$	0.00

.....

.....

.....

.....

.....

(2)

(b) Use information from the table in part (a) to determine the minimum volume, in cm^3, of 0.500 mol dm^{-3} sulfuric acid that is required for a titre of 25.0 cm^3 of 0.0200 mol dm^{-3} potassium manganate(VII) solution.
Show your working.

.....

.....

.....

.....

.....

.....

(3)

(c) In each titration using potassium manganate(VII), a large excess of dilute sulfuric acid is used to avoid any possibility of the brown solid MnO_2 forming.

(i) Deduce a half-equation for the reduction of MnO_4^- ions in acidic solution to form MnO_2.

.....

.....

(1)

(ii) Give **two** reasons why it is essential to avoid this reaction in a titration between potassium manganate(VII) and iron(II) ions.

.....

.....

.....

.....

.....

(2)

(d) Potassium manganate(VII) is an oxidising agent.
Suggest **one** reason why a 0.0200 mol dm^{-3} solution of potassium manganate(VII) does **not** need to be kept away from flammable material.

.....

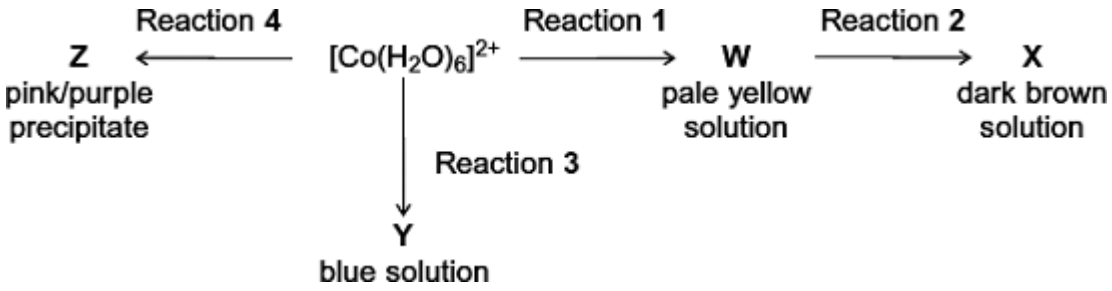
.....

.....

(1)
(Total 9 marks)

Q6. This question is about cobalt chemistry.

(a) Consider the following reaction scheme that starts from $[Co(H_2O)_6]^{2+}$ ions.
W, **X** and **Y** are ions and **Z** is a compound.



For each of the reactions **1** to **4**, identify a suitable reagent.

Identify **W**, **X**, **Y** and **Z** and write an equation for each of reactions **1** to **4**.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

.....

(12)

(b) A flue-gas desulfurisation process involves the oxidation, by oxygen, of aqueous sulfate(IV) ions (SO_3^{2-}) into aqueous sulfate(VI) ions (SO_4^{2-}). This reaction is

catalysed by Co^{2+} ions in an acidic aqueous solution.

Write an equation for the overall reaction of sulfate(IV) ions with oxygen to form sulfate(VI) ions.

Suggest why this overall reaction is faster in the presence of Co^{2+} ions.

Suggest a mechanism for the catalysed reaction by writing **two** equations involving Co^{2+} and Co^{3+} ions. You will need to use H^+ ions and H_2O to balance these two equations.

.....

.....

.....

.....

.....

.....

.....

.....

.....

(4)
(Total 16 marks)

Q1. Due to their electron arrangements, transition metals have characteristic properties including catalytic action and the formation of complexes with different shapes.

(a) Give **two other** characteristic properties of transition metals. For each property,illustrate your answer with a transition metal of your choice.

.....

.....

.....

.....

.....

.....

.....

.....

(4)

(b) Other than octahedral, there are several different shapes shown by transition metal complexes. Name **three** of these shapes and for each one give the formula of a complex with that shape.

.....

.....

.....

.....

.....

.....

.....

.....

.....

(6)

(c) It is possible for Group 2 metal ions to form complexes. For example, the $[Ca(H_2O)_6]^{2+}$ ion in hard water reacts with $EDTA^{4-}$ ions to form a complex ion in a similar manner to hydrated transition metal ions. This reaction can be used in a

titration to measure the concentration of calcium ions in hard water.

(i) Write an equation for the equilibrium that is established when hydrated calcium ions react with $EDTA^{4-}$ ions.

.....

(1)

(ii) Explain why the equilibrium in part (c)(i) is displaced almost completely to the right to form the EDTA complex.

.....

.....

.....

.....

.....

.....

(3)

(iii) In a titration, 6.25 cm^3 of a 0.0532 mol dm^{-3} solution of EDTA reacted completely with the calcium ions in a 150 cm^3 sample of a saturated solution of calcium hydroxide.
Calculate the mass of calcium hydroxide that was dissolved in 1.00 dm^3 of the calcium hydroxide solution.

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

.....

(3)
(Total 17 marks)

Q2. Iron is an important element in living systems. It is involved in redox and in acid–base reactions.

(a) Explain how and why iron ions catalyse the reaction between iodide ions and $S_2O_8^{2-}$ ions. Write equations for the reactions that occur.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Extra space) .....

.....

.....

(5)

(b) Iron(II) compounds are used as moss killers because iron(II) ions are oxidised in air to form iron(III) ions that lower the pH of soil.

(i) Explain, with the aid of an equation, why iron(III) ions are more acidic than iron(II) ions in aqueous solution.

.....

.....

.....

.....

.....

.....

(3)

(ii) In a titration, 0.321 g of a moss killer reacted with 23.60 cm^3 of acidified 0.0218 mol dm^{-3} $K_2Cr_2O_7$ solution.

Calculate the percentage by mass of iron in the moss killer. Assume that all of the iron in the moss killer is in the form of iron(II).

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(5)

(c) Some sodium carbonate solution was added to a solution containing iron(III) ions. Describe what you would observe and write an equation for the reaction that occurs.

.....

.....

.....

.....

.....

.....

(3)
(Total 16 marks)

Q3. The table below shows some standard electrode potentials.

			$E^{\ominus}$ / V
$MnO_4^- + 8H^+ + 5e^-$	⟶	$Mn^{2+} + 4H_2O$	+1.51
$Cl_2(g) + 2e^-$	⟶	$2Cl^-(aq)$	+1.36
$Cr_2O_7^{2-} + 14H^+ + 6e^-$	⟶	$2Cr^{3+} + 7H_2O$	+1.33

A student determined the concentration of iron(II) ions in a solution of iron(II) chloride by titration with acidified potassium dichromate(VI) solution. A second student titrated the same solution of iron(II) chloride with acidified potassium manganate(VII) solution.
By reference to the table, explain why the second student obtained a greater value for the concentration of iron(II) ions.

.....

.....

.....

.....

(Total 2 marks)

Q4.(a) When a solution containing iron(II) ions is treated with a slight excess of a solution containing ethanedioate ions a bright yellow precipitate of hydrated iron(II) ethanedioate, $FeC_2O_4.2H_2O$, is formed. The precipitate is filtered off, washed with propanone and then allowed to dry. A typical yield of the solid is 95%.

(i) Propanone boils at 56 °C and is miscible with water in all proportions. Suggest **two** reasons why washing with propanone is an effective method for producing a pure, dry precipitate.

Reason 1 .....

.....

Reason 2 .....

.....

(2)

(ii) By suggesting a simple test tube reaction, state how the filtrate could be tested to show that all of the iron(II) ions have been removed from the solution. State what you would observe.

Test .....

Observation .....

(2)

(iii) Suggest **one** reason why the typical yield of iron(II) ethanedioate is less than 100%.

.....

.....

(1)

(iv) Calculate the mass of hydrated iron(II) ethanedioate, $FeC_2O_4.2H_2O$ that can be formed from 50.0 cm^3 of a 0.50 mol dm^{-3} solution of iron(II) sulfate when the yield of the reaction is 95%. Show your working.

.....

.....

.....

.....

.....

(3)

(v) The identity of the precipitate can be confirmed by dissolving it in sulfuric acid and titrating the mixture with potassium manganate(VII).

Deduce the number of moles of iron(II) ethanedioate that would react with one mole of potassium manganate(VII) in acidic solution.

.....

.....

(1)

(b) Ethanedioate ions can be used to remove calcium ions from blood plasma. A precipitate of calcium ethanedioate is formed. Write an ionic equation for the reaction of ethanedioate ions with calcium ions.

.....

.....

(1)

(c) Ethanedioic acid is used to clean marble, a form of calcium carbonate. Suggest **one** reason why the reaction between ethanedioic acid and marble stops after a short time.

.....

.....

(1)

(d) Tea leaves contain ethanedioic acid. Suggest **one** reason why tea drinkers do **not** suffer from ethanedioic acid poisoning.

.....

(1)

(e) Ethanedioic acid is produced by the oxidation of carbon monoxide in a multi-step process. The equation which summarises the reactions taking place is shown below.

$$4CO + 4NaOH + O_2 + 4HCl \rightarrow 2H_2C_2O_4 + 4NaCl + 2H_2O$$

Calculate the percentage atom economy for the formation of ethanedioic acid in this reaction. Show your working.

.....

.....

.....

(2)

(Total 14 marks)

Q1. A 0.263 g sample of impure iron, containing an unreactive impurity, was reacted with an excess of hydrochloric acid. All of the iron in the sample reacted, evolving hydrogen gas and forming a solution of iron(II) chloride. The volume of hydrogen evolved was 102 cm^3, measured at 298 K and 110 kPa.

The percentage, by mass, of iron in the sample can be determined using either the volume of hydrogen produced or by titrating the solution of iron(II) chloride formed against a standard solution of potassium dichromate(VI).

(a) (i) Write an equation for the reaction between iron and hydrochloric acid.

.....

(ii) Calculate the number of moles of hydrogen produced in the reaction.

.....

.....

.....

.....

(iii) Use your answers to parts (a)(i) and (ii) to determine the number of moles of iron and the mass of iron in the original sample. (If you have been unable to complete part (a)(ii) you should assume the answer to be 4.25×10^{-3} mol. This is not the correct answer.)

Moles of iron .....

Mass of iron .....

(iv) Calculate the percentage of iron in the original sample.

.....

.....

(7)

(b) (i) Write half-equations for the oxidation of Fe^{2+} and for the reduction of $Cr_2O_7^{2-}$ in acidic solution, and use these to construct an overall equation for the reaction between these two ions.

Half-equation for the oxidation of Fe^{2+}

.....

Half-equation for the reduction of $Cr_2O_7^{2-}$

.....

Overall equation

.....

(ii) The number of moles of iron in the sample was determined in part (a)(iii). Use this answer to calculate the volume of a 0.0200 mol dm^{-3} solution of potassium dichromate(VI) which would react exactly with the solution of iron(II) chloride formed in the reaction.

(If you have been unable to complete part (a)(iii) you should assume the answer to be 3.63×10^{-3} mol. This is not the correct answer.)

.....

.....

.....

.....

.....

(iii) Explain why an incorrect value for the number of moles of iron(II) chloride formed would have been obtained if the original solution had been titrated with potassium manganate(VII).

.....

.....

(7)
(Total 14 marks)

Q2. (a) State the electron configuration of a Ti(III) ion and that of a Ti(IV) ion. Explain, in terms of electron configurations and electron transitions, why Ti(III) compounds are usually coloured but Ti(IV) compounds are colourless.

.....

.....

.....

.....

.....

.....

.....

.....

.....

(5)

(b) Transition metal ions and their complexes can often be identified from their colours. For each of the following, identify a complex ion responsible for the colour of the aqueous solution. Restrict your answers to complexes formed from the elements Cr, Fe, Co and Cu.

A deep blue solution formed in an excess of concentrated aqueous ammonia.

A green solution formed in an excess of aqueous sodium hydroxide.

A yellow–green solution formed in an excess of concentrated hydrochloric acid.

.....

.....

.....

.....

.....

.....

(3)

(c) An experiment is carried out to investigate the rate of the autocatalysed reaction between aqueous potassium manganate(VII) and ethanedioate ions in an excess of dilute sulfuric acid. When these reagents are mixed together, the colour of the reaction mixture gradually fades. The concentration of the manganate(VII) ions is recorded at different times using a spectrometer. The temperature of the reaction mixture is constant.

(i) Give **two** reasons why the use of a spectrometer is the most appropriate method for measuring the concentration of the coloured ions in this experiment.

.....

.....

.....

.....

(2)

(ii) Sketch a curve to show how you would expect the concentration of manganate(VII) ions to change with time until the colour has faded because the concentration has reached a very low value. Explain the shape of the curve.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(5)
(Total 15 marks)

Q3. (a) When aqueous ammonia was added to an aqueous solution of cobalt(II) sulfate, a blue precipitate **M** was formed. Identify the cobalt-containing species present in aqueous cobalt(II) sulphate and in the precipitate **M**.

Cobalt-containing species .....

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

(2)

(b) 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**.

.....

(1)

(c) 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 .....

(2)

(d) When potassium iodide was added to the solution containing **Q** and the mixture was acidified, a dark brown solution due to the presence of **R** was formed. On addition of starch solution the mixture turned blue-black.

Identify **R** and explain its formation.

*Identity of **R*** .....

Explanation .....

(2)
(Total 7 marks)

Q4. When anhydrous iron(III) chloride is added to water the following reactions occur.

$$FeCl_3 + 6H_2O \rightarrow [Fe(H_2O)_6]^{3+} + 3Cl^-$$

$$[Fe(H_2O)_6]^{3+} + H_2O \rightarrow [Fe(H_2O)_5(OH)]^{2+} + H_3O^+$$

(a) State the type of acidity shown by $FeCl_3$ and by $[Fe(H_2O)_6]^{3+}$ in these reactions. Explain your answers.

(4)

(b) Explain why the pH of a solution of iron(II) chloride is higher than that of a solution of iron(III) chloride of the same concentration.

(2)

(c) Transition metals have variable oxidation states. This is an important factor in their ability to act as heterogeneous and homogeneous catalysts.

(i) Vanadium(V) oxide acts as a heterogeneous catalyst in the Contact Process. Write equations to show the role of vanadium(V) oxide in this process.

(ii) In aqueous solution, Fe^{2+} ions act as a homogeneous catalyst in the reaction between I^- and $S_2O_8^{2-}$ ions. Give one reason why the reaction is slow in the absence of a catalyst. Write equations to show how Fe^{2+} ions act as a catalyst for this reaction.

(7)
(Total 13 marks)

Q5. Iron from the Blast Furnace contains carbon. In the steel-making process, oxygen is blown through molten impure iron. At stages during this process samples of iron are taken and analysed to determine the remaining carbon content. One method of analysis involves a redox titration.

At one stage a 1.27g sample of this impure iron was reacted with an excess of dilute sulphuric acid. All of the iron in the sample was converted into iron(II) sulfate, and hydrogen was evolved. The solution formed was made up to 250 cm^3. A 25.0 cm^3 sample

of this solution reacted completely with exactly 19.6 cm^3 of a 0.0220 mol dm^{-1} solution of potassium manganate(VII).

(a) Write an equation for the reaction between iron and dilute sulphuric acid.

.....

(1)

(b) Write an equation for the reaction of iron(II) ions with manganate(VII) ions in acid solution.

.....

.....

.....

(1)

(c) Assuming that carbon is the only impurity, calculate the percentage by mass of carbon in the 1.27g sample.

.....

.....

.....

.....

.....

(5)

(d) How would you ensure the reliability of the result obtained in this experiment?

.....

(1)

(e) Suggest one way in which the reliability of this analysis could be improved.

.....

(1)

(Total 9 marks)

Q1. When vanadium reacts with chlorine at 400°C, a brown compound is obtained. When an aqueous solution containing 0.193 g of this compound was treated with aqueous silver nitrate all the chlorine in the compound was precipitated as silver chloride. The mass of silver chloride (AgCl) produced was 0.574 g. Which one of the following could be the formula of the brown compound?

A VCl

B VCl_2

C VCl_3

D VCl_4

(Total 1 mark)

Q2. The oxidation of ethanedioate (*oxalate*) ions by manganate(VII) ions can be represented by the half equations:

$$C_2O_4^{2-}(aq) \rightarrow 2CO_2(g) + 2e^-$$

$$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightarrow Mn^{2+}(aq) + 4H_2O(l)$$

What volume (in cm^3) of 0.02 M $KMnO_4$ is required to oxidise completely a solution containing 0.02 mol of ethanedioate ions?

A 25

B 40

C 250

D 400

(Total 1 mark)

Q3. Which one of the following can act as an oxidising agent but not as a reducing agent?

A CH_3CHO

B Fe^{2+}

C I^-

D MnO_4^-

(Total 1 mark)

Q4. In which one of the following reactions does the metal species undergo reduction?

A $MnO_2 + 4HCl \rightarrow MnCl_2 + 2H_2O + Cl_2$

B $[Cu(H_2O)_6]^{2+} + 4Cl^- \rightarrow [CuCl_4]^{2-} + 6H_2O$

C $CrO_7^{2-} + 2OH^- \rightarrow 2CrO_4^{2-} + H_2O$

D $TiO_2 + 2C + 2Cl_2 \rightarrow TiCl_4 + 2CO$

(Total 1 mark)

Q5. The percentage of iron in a sample of impure iron(II) sulphate crystals can be determined by titrating solutions, made from separate weighed samples acidified with dilute sulphuric acid, against a standard solution of potassium manganate(VII).

Which one of the following would lead to the greatest error in the calculation of the percentage of iron(II) in the sample?

A an error of 0.005 g made when weighing out a sample of mass 0.987 g

B an end-point error of 0.1 cm^3 in 25.0 cm^3

C an error of 5 cm^3 when measuring out 25.0 cm^3 of dilute sulphuric acid

D using the average of the titration values 25.4, 25.7 and 25.9 when the correct value is 25.5 cm^3

(Total 1 mark)

Q6. The percentage of iron in a sample of impure iron(II) sulphate crystals can be determined by titrating solutions, made from separate weighed samples acidified with dilute sulphuric acid, against a standard solution of potassium manganate(VII).

Which one of the following would lead to an inaccurate result?

A transferring the weighed sample of iron(II) sulphate into a wet conical flask

B failing to measure accurately the volume of water used to dissolve each weighed sample of iron(II) sulphate

C transferring the standard solution of potassium manganate(VII) from its original container to the burette using a wet beaker

D failing to measure accurately the volume of dilute sulphuric acid added to the

mixture before titration

(Total 1 mark)

Q7. Aqueous $C_2O_4^{2-}$ ions react with MnO_4^- ions in acidic solution according to the equation

$$5\ C_2O_4^{2-} + 2MnO_4^- + 16H^+ \rightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$$

Under the same conditions Fe^{2+} ions also react with MnO_4^- ions. How many moles of MnO_4^- ions are required to react exactly with one mole of $Fe(C_2O_4).2H_2O$?

A 0.4

B 0.6

C 2.5

D 7.5

(Total 1 mark)

Q8. The percentage of iron in a sample of impure iron(II) sulphate crystals can be determined by titrating solutions, made from separate weighed samples acidified with dilute sulphuric acid, against a standard solution of potassium manganate(VII).

Which one of the following statements explains why dilute hydrochloric acid is unsuitable for use in this titration?

A HCl will oxidise Fe^{2+} to Fe^{3+}

B Cl^- will reduce Fe^{3+} to Fe^{2+}

C Cl^- will reduce MnO_4^-

D HCl is a strong acid

(Total 1 mark)

Q9. Which one of the following statements about the reaction below is **false**?

$$[Cu(H_2O)_6]^{2+} + EDTA^{4-} \rightleftharpoons [Cu(EDTA)]^{2-} + 6H_2O$$

A $[Cu(EDTA)]^{2-}$ is a more stable complex than $[Cu(H_2O)_6]^{2+}$

B Both $[Cu(H_2O)_6]^{2+}$ and $[Cu(EDTA)]^{2-}$ are octahedral complexes.

C There is an increase in entropy when the reaction occurs.

D There is a redox reaction.

(Total 1 mark)

Q10. Where appropriate, use the standard electrode potential data in the table below to answer the questions which follow.

							$E^{\ominus}$/V
$Zn^{2+}(aq)$	+	$2e^-$	→	$Zn(s)$			–0.76
$V^{3+}(aq)$	+	e^-	→	$V^{2+}(aq)$			–0.26
$SO_4^{2-}(aq) + 2H^+(aq)$	+	$2e^-$	→	$SO_3^{2-}(aq)$	+	$H_2O(l)$	+0.17
$VO^{2+}(aq) + 2H^+(aq)$	+	e^-	→	$V^{3+}(aq)$	+	$H_2O(l)$	+0.34
$Fe^{3+}(aq)$	+	e^-	→	$Fe^{2+}(aq)$			+0.77
$VO_2^+(aq) + 2H^+(aq)$	+	e^-	→	$VO^{2+}(aq)$	+	$H_2O(l)$	+1.00
$Cl_2(aq)$	+	$2e^-$	→	$2Cl^-(aq)$			+1.36

(a) From the table above select the species which is the most powerful reducing agent.

.....

(1)

(b) From the table above select

(i) a species which, in acidic solution, will reduce $VO_2^+(aq)$ to $VO^{2+}(aq)$ but will **not** reduce $VO^{2+}(aq)$ to $V^{3+}(aq)$,

.....

(ii) a species which, in acidic solution, will oxidise $VO^{2+}(aq)$ to $VO_2^+(aq)$.

.....

(2)

(c) The cell represented below was set up under standard conditions.

$Pt|Fe^{2+}(aq), Fe^{3+}(aq)||Tl^{3+}(aq), Tl^{+}(aq)|Pt$ Cell e.m.f. = + 0.48 V

(i) Deduce the standard electrode potential for the following half-reaction.

$Tl^{3+}(aq) + 2e^{-} \rightarrow Tl^{+}(aq)$

.....

.....

(ii) Write an equation for the spontaneous cell reaction.

.....

(3)

(d) After acidification, 25.0 cm^3 of a solution of hydrogen peroxide reacted exactly with 16.2 cm^3 of a 0.0200 mol dm^{-3} solution of potassium manganate(VII). The overall equation for the reaction is given below.

$2MnO_4^- + 6H^+ + 5H_2O_2 \rightarrow 2Mn^{2+} + 8H_2O + 5O_2$

(i) Use the equation for this reaction to determine the concentration, in g dm^{-3}, of the hydrogen peroxide solution.

.....

.....

.....

.....

.....

.....

(ii) Calculate the maximum volume of oxygen, measured at a pressure of 98 kPa and a temperature of 298 K, which would be evolved in this reaction.

.....

.....

.....

.....

.....

(8)
(Total 14 marks)

Q11. Which one of the following would **not** reduce an acidified aqueous solution of potassium dichromate(VI)?

A CH_3COOH

B Zn

C CH_3CHO

D $Fe^{2+}(aq)$

(Total 1 mark)

Q12. (a) "The strength of adsorption onto the active sites on the surface of a heterogeneous catalyst helps to determine the activity of the catalyst."

Explain how heterogeneous catalysts work, give **one** example of a reaction catalysed in this way and discuss why different catalysts have different activities.

(8)

(b) Outline a plan of an experiment to determine the percentage of iron present as iron(III) in a solution containing $Fe^{3+}(aq)$ and $Fe^{2+}(aq)$ ions. You are provided with zinc, a standard solution of potassium dichromate(VI) and dilute sulphuric acid. Zinc can reduce $Fe^{3+}(aq)$ to $Fe^{2+}(aq)$.

Write equations for all the reactions that occur. Explain how you would use the zinc and how you would calculate the final answer.

(7)
(Total 15 marks)

Q13. Use your knowledge of the chemistry of transition metals to predict which of the following will convert $[Mn(H_2O)_6]^{2+}$ into MnO_4^{2-}

A an acid and a reducing agent

B an acid and an oxidising agent

C an alkali and a reducing agent

D an alkali and an oxidising agent

(Total 1 mark)

Q14. A 0.0720 g sample of reducing agent **R** was dissolved in water and acidified with an excess of dilute H_2SO_4. The resulting solution was found to react with exactly 18.0 cm^3 of a 0.0200 mol dm^{-3} solution of $KMnO_4$.

In this reaction, 5 mol of **R** react with 3 mol of $KMnO_4$. The M_r of **R** is

A 120

B 167

C 240

D 333

(Total 1 mark)

Q15. (a) Vanadium(V) oxide is used as a heterogeneous catalyst in the Contact Process.

Explain what is meant by the terms *heterogeneous* and *catalyst* and state, in general terms, how a catalyst works.

State the essential feature of vanadium chemistry which enables vanadium(V) oxide to function as a catalyst and, by means of equations, suggest how it might be involved in the Contact Process.

(7)

(b) The following method was used to determine the percentage by mass of vanadium in a sample of ammonium vanadate(V).

A solution was made up by dissolving 0.160 g of ammonium vanadate(V) in dilute sulphuric acid. The ammonium vanadate(V) formed VO_2^+ ions in this solution. When an excess of zinc was added to this solution, the VO_2^+ ions were reduced to V^{2+} ions and the zinc was oxidised to Zn^{2+} ions.

After the unreacted zinc had been removed, the solution was titrated against a 0.0200 mol dm^{-3} solution of potassium manganate(VII). In the titration, 38.5 cm^3 of potassium manganate(VII) solution were required to oxidise all vanadium(II) ions to vanadium(V) ions.

Using half-equations, construct an overall equation for the reduction of VO_2^+ to V^{2+} by zinc in acidic solution.

Calculate the percentage by mass of vanadium in the sample of ammonium vanadate(V).

(8)
(Total 15 marks)

Q16. The vanadium does **not** have an oxidation state of +3 in

A $[V(H_2O)_6]^{3+}$

B $[V(C_2O_4)_3]^{3-}$

C $[V(OH)_3(H_2O)_3]$

D $[VCl_4]^{3-}$

(Total 1 mark)