

1

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

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(6)

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

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(1)

(c) Suggest **one** reason why electron pair repulsion theory **cannot** be used to predict the shape of the $[\text{CoCl}_4]^{2-}$ ion.

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(1)

(d) Predict the shape of, and the bond angle in, the complex rhodium ion $[\text{RhCl}_4]^{2-}$.

Shape

Bond angle

(2)

(Total 10 marks)

2

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)

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(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.

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(2)

(e) The vanadium in 50.0 cm^3 of a $0.800 \text{ mol dm}^{-3}$ solution of NH_4VO_3 reacts with 506 cm^3 of sulfur(IV) oxide gas measured at $20.0 \text{ }^\circ\text{C}$ 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 $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$.

Oxidation state =

(6)
(Total 11 marks)

3

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

Explain how this co-ordinate bond is formed.

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(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.

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(4)

(c) When the complex ion $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ reacts with 1,2-diaminoethane, the ammonia molecules but not the water molecules are replaced.

Write an equation for this reaction.

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(1)

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

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(2)

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

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(2)

(Total 11 marks)

4

A green solution, **X**, is thought to contain $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$ 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.

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(4)

- (b) A 50.0 cm³ sample of solution **X** was added to 50 cm³ of dilute sulfuric acid and made up to 250 cm³ of solution in a volumetric flask.

A 25.0 cm³ sample of this solution from the volumetric flask was titrated with a 0.0205 mol dm⁻³ solution of KMnO₄

At the end point of the reaction, the volume of KMnO₄ solution added was 18.70 cm³.

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

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(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**.

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(5)
(Total 11 marks)

5

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.

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(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.

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(4)

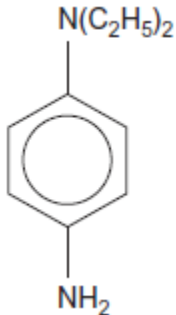
(Total 10 marks)

6

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.

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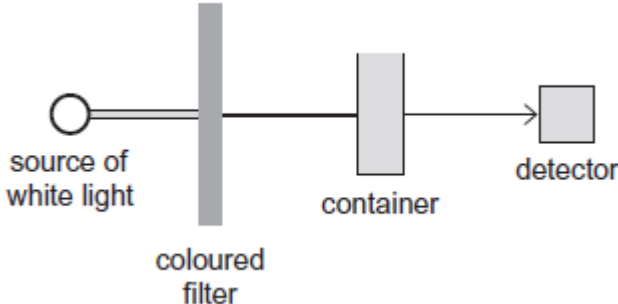
(1)

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

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(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.

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(1)

(ii) Suggest why the coloured filter is used.

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(1)

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

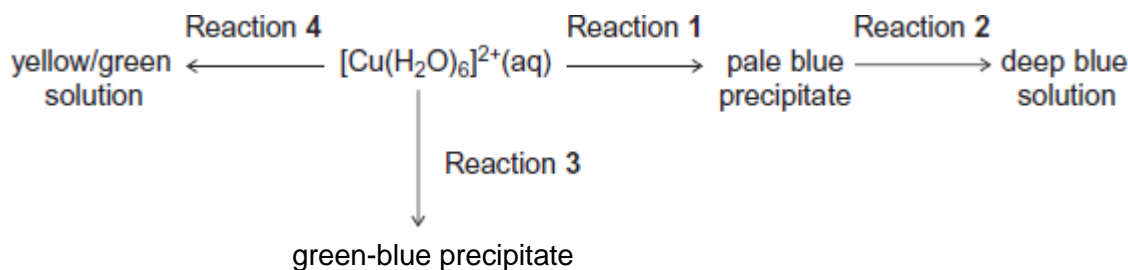
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(1)

(Total 5 marks)

7

Consider the following reaction scheme that starts from aqueous $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ 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)

8

The characteristic properties of transition metals include coloured ions, complex formation and catalytic activity.

(a) Consider the chromium complexes **P** and **Q**.



Explain, with reference to oxidation states and electron configurations, why the chromium ions in complexes **P** and **Q** contain the same number of d electrons.

You should **not** consider the electrons donated by the ligands.

- (b) Write an equation to show how the $[\text{Co}(\text{NH}_3)_6]^{2+}(\text{aq})$ ion reacts with 1,2-diaminoethane. Explain the thermodynamic reasons why this reaction occurs.

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(5)

- (c) The toxic complex cisplatin is an effective anti-cancer drug because it reacts with the DNA in cancer cells, preventing cell division.

- (i) Draw the **displayed** structure of cisplatin.
On your structure, show the value of one of the bond angles at platinum.
State the charge, if any, on the complex.

(3)

- (ii) When cisplatin is ingested, an initial reaction involves one of the chloride ligands being replaced by water.

Write an equation for this reaction.

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(1)

(iii) Suggest how the risk associated with the use of this drug can be minimised.

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(1)

(d) Explain, with the aid of equations, how and why vanadium(V) oxide is used in the Contact Process.

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(4)

(Total 20 marks)

9

A student carried out an experiment to find the mass of $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ 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 $0.0150 \text{ mol dm}^{-3}$ solution of $\text{K}_2\text{Cr}_2\text{O}_7$

(a) Use this information to calculate a value for the mass of $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ in the sample of **X**.

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(5)

(b) The student found that the calculated mass of $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ 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 $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ in **X** to be greater than the actual mass of **X**.
Explain your answer.

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(2)
(Total 7 marks)

10

When iodine molecules are dissolved in aqueous solutions containing iodide ions, they react to form triiodide ions (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.

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(1)

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

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(1)

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

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(1)

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

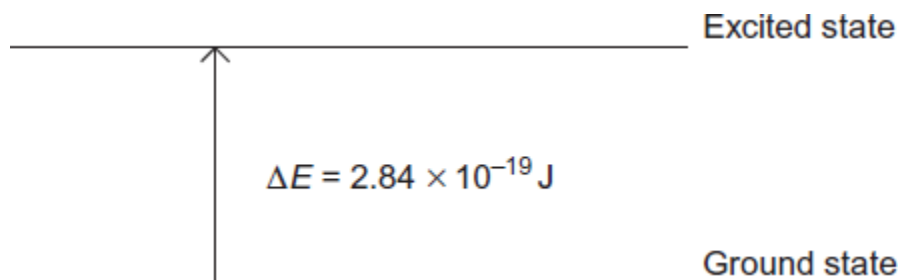
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(1)

(Total 4 marks)

11

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 ν .

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 $h = 6.63 \times 10^{-34} \text{ J s}$.

Equation

Calculation

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(2)

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

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(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

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(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

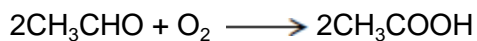
(3)

(Total 9 marks)

12

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



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.

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(4)

(b) In aqueous solution, the $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ 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 $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ complex ion.

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(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 cm³ 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.

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(5)
(Total 15 marks)

13

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.

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(3)

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

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(1)

(Total 4 marks)

14

Iron(II) ethanedioate is another insoluble solid used as a pigment in paints and glass. It occurs as a dihydrate ($\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$). One procedure used for the preparation of iron(II) ethanedioate is outlined below.

Procedure

A 6.95 g sample of hydrated iron(II) sulfate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) was added to 100 cm³ of water in a beaker and stirred until all of the solid dissolved. A 150 cm³ 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 ($\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$) were collected.

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

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(1)

(b) Calculate the amount, in moles, of $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ in 6.95 g of hydrated iron(II) sulfate. Show your working.

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(2)

- (c) Calculate the amount, in moles, of sodium ethanedioate in 150 cm³ of 0.20 mol dm⁻³ sodium ethanedioate solution.

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(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.

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(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%.

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(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.

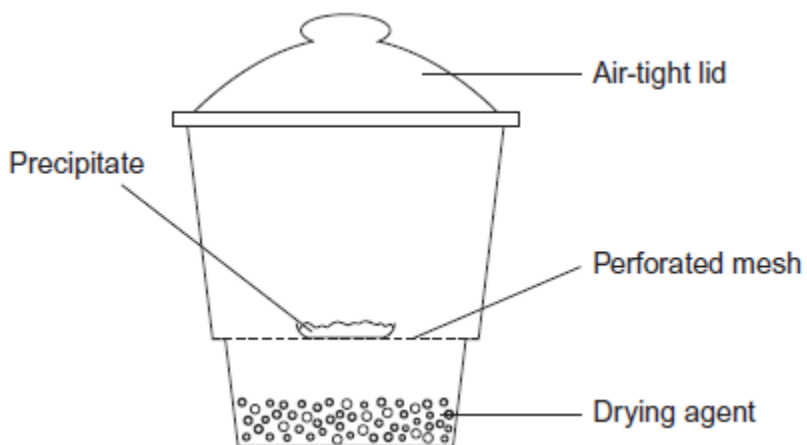
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(2)

(Total 9 marks)

15

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



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

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(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.

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(1)
(Total 2 marks)

16

An equation for the decomposition of hydrogen peroxide is



- (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.

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(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).

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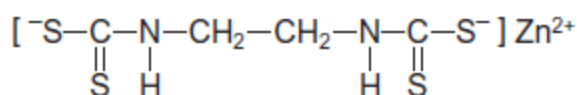
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(2)
(Total 6 marks)

17

- (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.

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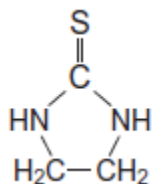
(1)

- (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.

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(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 ($M_r = 102.1$).

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(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.

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(4)

(Total 8 marks)

18

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.

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(1)

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

Equation 1

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Equation 2

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(2)

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

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

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(1)

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

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(1)

- (d) The oxidation of $\text{C}_2\text{O}_4^{2-}$ 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*.

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(1)

- (ii) Identify the autocatalyst in this reaction.

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(1)

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

Equation 1

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Equation 2

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(2)
(Total 9 marks)

19

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

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(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 $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ ion.

Explain why these complex ions have different colours.

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(3)

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

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(2)

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

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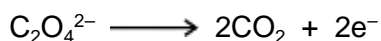
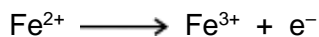
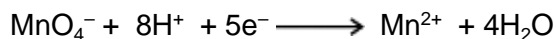
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- (d) Iron(II) ethanedioate dihydrate can be analysed by titration using potassium manganate(VII) in acidic solution. In this reaction, manganate(VII) ions oxidise iron(II) ions and ethanedioate ions.

A 1.381 g sample of impure $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ 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 $0.0193 \text{ mol dm}^{-3}$ 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.



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(1)

(ii) Calculate the percentage by mass of $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ 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.)

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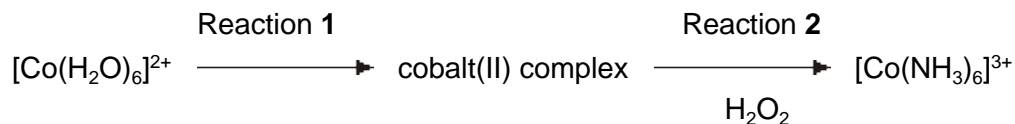
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(5)
(Total 10 marks)

21

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.



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

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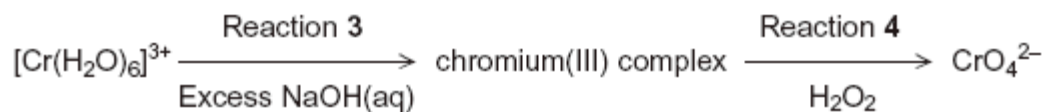
(3)

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

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(1)

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



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

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(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.

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(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 cm³ sample of the hydrogen peroxide solution was added to a volumetric flask and made up to 250 cm³ of aqueous solution. A 25.0 cm³ sample of this diluted solution was acidified and reacted completely with 24.35 cm³ 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 KMnO₄ react with 7mol of H₂O₂. This is **not** the correct reacting ratio.)

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(5)
(Total 17 marks)

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	$\Delta H^\ominus / \text{kJ mol}^{-1}$
$\text{Ca(s)} \rightarrow \text{Ca(g)}$	+193
$\text{Ca(g)} \rightarrow \text{Ca}^+(\text{g}) + \text{e}^-$	+590
$\text{Ca}^+(\text{g}) \rightarrow \text{Ca}^{2+}(\text{g}) + \text{e}^-$	+1150
$\text{F}_2(\text{g}) \rightarrow 2\text{F}(\text{g})$	+158
$\text{F}(\text{g}) + \text{e}^- \rightarrow \text{F}^-(\text{g})$	-348

Table 2

Name of enthalpy change	$\Delta H^\ominus / \text{kJ mol}^{-1}$
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*.

.....

.....

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(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.

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(3)

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

.....

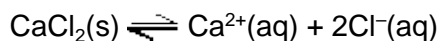
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(2)

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



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

.....

.....

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(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

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.....

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(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.

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(2)

(Total 17 marks)

23

Transition metal ions can act as homogeneous catalysts in redox reactions. For example, iron(II) ions catalyse the reaction between peroxodisulfate ($\text{S}_2\text{O}_8^{2-}$) 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)

24

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*.

.....
.....
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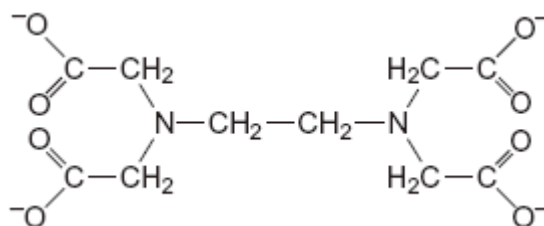
(2)

(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 $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ ion. Use the abbreviation EDTA^{4-} in your equation.

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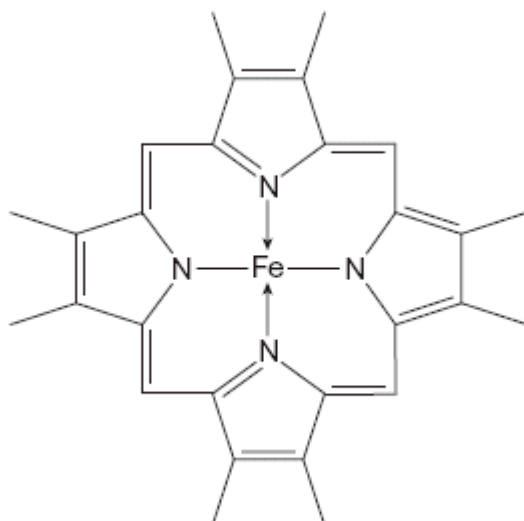
(1)

(iii) Explain why the complex ion, formed as a product of the reaction in part (d) (ii), is more stable than the $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ 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 $N \rightarrow Fe$ and as $N - Fe$.

State the meaning of each of these symbols.

Meaning of \rightarrow

Meaning of $-$

(2)

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

.....

(1)

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

.....

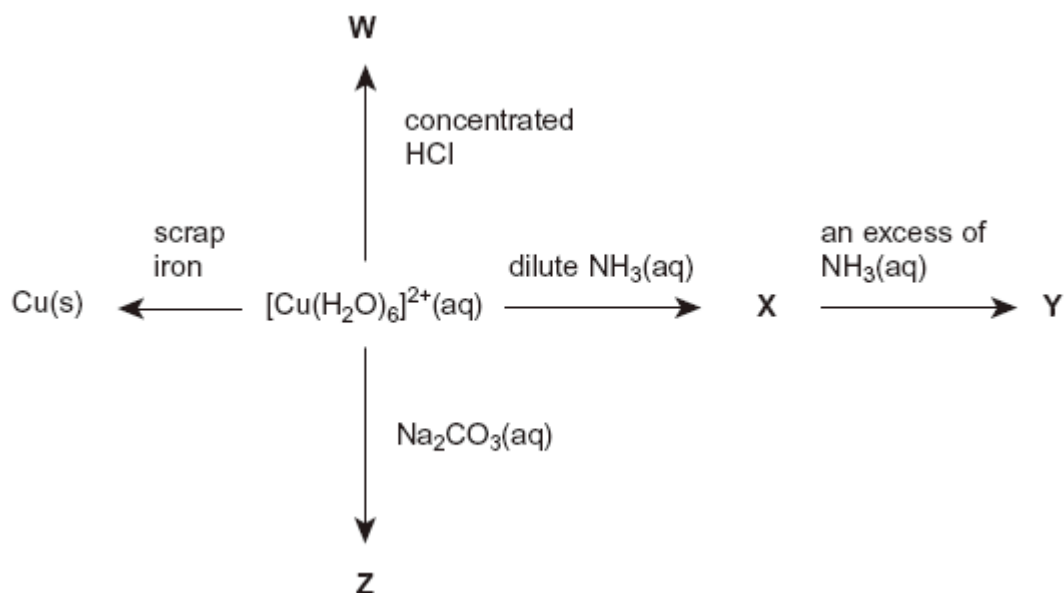
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.....

(2)
(Total 16 marks)

25

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 $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$ ions.

Ion **W**.....

Appearance

Equation

(3)

- (b) Identify compound **X**. Describe its appearance and write an equation for its formation from $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$ 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 $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$ 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

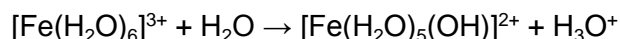
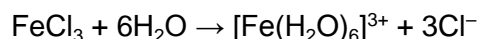
Reason 2

(2)

(Total 17 marks)

26

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



- (a) State the type of acidity shown by FeCl_3 and by $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$ 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 $\text{S}_2\text{O}_8^{2-}$ 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)

27

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 $4.25 \times 10^{-3} \text{ mol}$. 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 $\text{Cr}_2\text{O}_7^{2-}$ 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 $\text{Cr}_2\text{O}_7^{2-}$

.....

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 $0.0200 \text{ mol dm}^{-3}$ 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 $3.63 \times 10^{-3} \text{ mol}$. This is not the correct answer.)

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- (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)

(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 $[\text{CuCl}_4]^{3-}$ is +1.

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

.....

- (ii) Deduce the role of copper metal in the formation of $[\text{CuCl}_4]^{3-}$ from the copper-containing species in solution **D**.
-

(2)
(Total 17 marks)

30

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

						E^\ominus/V
$\text{Zn}^{2+}(\text{aq})$	+	2e^-	\rightarrow	$\text{Zn}(\text{s})$		
<hr/>						
$\text{V}^{3+}(\text{aq})$	+	e^-	\rightarrow	$\text{V}^{2+}(\text{aq})$		
<hr/>						
$\text{SO}_4^{2-}(\text{aq}) + 2\text{H}^+(\text{aq})$	+	2e^-	\rightarrow	$\text{SO}_3^{2-}(\text{aq})$	+	$\text{H}_2\text{O}(\text{l})$
<hr/>						
$\text{VO}^{2+}(\text{aq}) + 2\text{H}^+(\text{aq})$	+	e^-	\rightarrow	$\text{V}^{3+}(\text{aq})$	+	$\text{H}_2\text{O}(\text{l})$
<hr/>						
$\text{Fe}^{3+}(\text{aq})$	+	e^-	\rightarrow	$\text{Fe}^{2+}(\text{aq})$		
<hr/>						
$\text{VO}_2^+(\text{aq}) + 2\text{H}^+(\text{aq})$	+	e^-	\rightarrow	$\text{VO}^{2+}(\text{aq})$	+	$\text{H}_2\text{O}(\text{l})$
<hr/>						
$\text{Cl}_2(\text{aq})$	+	2e^-	\rightarrow	$2\text{Cl}^-(\text{aq})$		
<hr/>						

- (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 $\text{VO}_2^+(\text{aq})$ to $\text{VO}^{2+}(\text{aq})$ but will **not** reduce $\text{VO}^{2+}(\text{aq})$ to $\text{V}^{3+}(\text{aq})$,
-

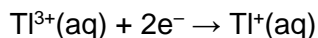
- (ii) a species which, in acidic solution, will oxidise $\text{VO}^{2+}(\text{aq})$ to $\text{VO}_2^+(\text{aq})$.
-

(2)

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



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



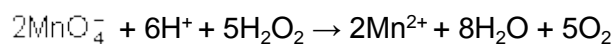
.....
.....

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

.....

(3)

(d) After acidification, 25.0 cm³ of a solution of hydrogen peroxide reacted exactly with 16.2 cm³ of a 0.0200 mol dm⁻³ solution of potassium manganate(VII). The overall equation for the reaction is given below.



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

.....
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.....
.....
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.....

- (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.

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.....

(8)
(Total 14 marks)

- 31** (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 $\text{S}_2\text{O}_8^{2-}$ 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)

(5)
(Total 17 marks)

- 32** (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)

(8)

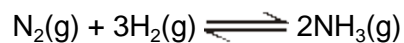
- (c) The frequency, ν , of light absorbed by a transition metal complex ion can be determined using the relationship $\Delta E = h\nu$. State what is meant by the symbols ΔE and h . Give **three** factors which result in a change in the frequency of light absorbed as a result of the reaction of a complex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

(5)

(Total 16 marks)

33

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



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)

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(Total 9 marks)

34

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 $0.0200 \text{ mol dm}^{-3}$ 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)

35

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

- A $[\text{V}(\text{H}_2\text{O})_6]^{3+}$
- B $[\text{V}(\text{C}_2\text{O}_4)_3]^{3-}$
- C $[\text{V}(\text{OH})_3(\text{H}_2\text{O})_3]$
- D $[\text{VCl}_4]^{3-}$

(Total 1 mark)

36

(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^- , $\text{C}_2\text{O}_4^{2-}$ 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)

Mark schemes

- 1** (a) This question is marked using levels of response. Refer to the Mark Scheme Instructions for Examiners for guidance on how to mark this question.

All stages are covered and the explanation of each stage is generally correct and virtually complete.

Answer is communicated coherently and shows a logical progression from stage 1 to stage 2 then stage 3.

Level 3
5 – 6 marks

All stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies OR two stages are covered and the explanations are generally correct and virtually complete.

Answer is mainly coherent and shows progression from stage 1 to stage 3.

Level 2
3 – 4 marks

Two stages are covered but the explanation of each stage may be incomplete or may contain inaccuracies, OR only one stage is covered but the explanation is generally correct and virtually complete

Answer includes isolated statements but these are not presented in a logical order or show confused reasoning.

Level 1
1 – 2 marks

Insufficient correct chemistry to gain a mark.

Level 0
0 marks

Indicative chemistry content

Stage 1: Electrons round P

- P has 5 electrons in the outside shell
- With 3 electrons from 3 fluorine, there are a total of 8 electrons in outside shell
- so 3 bond pairs, 1 non-bond pair

Stage 2: Electron pair repulsion theory

- Electron pairs repel as far as possible
- Lone pair repels more than bonding pairs

Stage 3: Conclusions

- Therefore, tetrahedral / trigonal pyramidal shape
- With angle of 109.5° decreased to 107°

6

- (b) $1s^22s^22p^63s^23p^63d^7$

Allow correct numbers that are not superscripted

1

- (c) Too many electrons in d sub-shell / orbitals

1

- (d) Tetrahedral (shape) 1
109.5°
Allow 109°

1
[10]

2

- (a) Y 1
(b) X 1

- (c) Jump in trend of ionisation energies after removal of fifth electron
Fits with an element with 5 outer electrons (4s²3d³) like V 1

- (d) Explanation: Two different colours of solution are observed 1
Because each colour is due to vanadium in a different oxidation state 1

- (e) **Stage 1:** mole calculations in either order
Moles of vanadium = $50.0 \times 0.800 / 1000 = 4.00 \times 10^{-2}$
Extended response
Maximum of 5 marks for answers which do not show a sustained line of reasoning which is coherent, relevant, substantiated and logically structured. 1

Moles of SO₂ = $pV / RT = (98\ 000 \times 506 \times 10^{-6}) / (8.31 \times 293)$
= 2.04×10^{-2} 1

Stage 2: moles of electrons added to NH₄VO₃
When SO₂ (sulfur(IV) oxide) acts as a reducing agent, it is oxidised to sulfate(VI) ions so this is a two electron change 1

Moles of electrons released when SO₂ is oxidised = $2.04 \times 10^{-2} \times 2$
= 4.08×10^{-2} 1

Stage 3: conclusion
But in NH₄VO₃ vanadium is in oxidation state 5 1

4.00×10^{-2} mol vanadium has gained 4.08×10^{-2} mol of electrons
 therefore 1 mol vanadium has gained $4.08 \times 10^{-2} / 4.00 \times 10^{-2} = 1$ mol
 of electrons to the nearest integer, so new oxidation state is $5 - 1 = 4$

1
 [11]

3

- (a) An electron pair on the ligand

1

Is donated from the ligand to the central metal ion

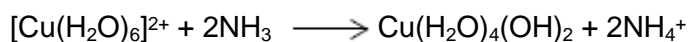
1

- (b) Blue precipitate

1

Dissolves to give a dark blue solution

1



1



1

- (c) $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+} + 2\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2 \longrightarrow [\text{Cu}(\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2)_2(\text{H}_2\text{O})_2]^{2+} + 4\text{NH}_3$

1

- (d) Cu–N bonds formed have similar enthalpy / energy to Cu–N bonds broken

1

And the same number of bonds broken and made

1

- (e) 3 particles form 5 particles / disorder increases because more particles are formed /
 entropy change is positive

1

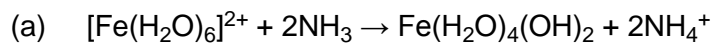
Therefore, the free-energy change is negative

M2 can only be awarded if M1 is correct

1

[11]

4

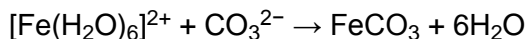


Allow equation with OH⁻ provided equation showing formation of OH⁻ from NH₃ given

1

Green precipitate

1



1

Green precipitate

effervescence incorrect so loses M4

1

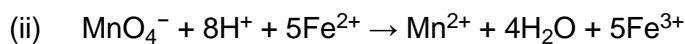
- (b) (i) Colourless / (pale) green changes to pink / purple (solution)

Do not allow pale pink to purple

1

Just after the end-point MnO_4^- is in excess / present

1



1

Moles $\text{KMnO}_4 = 18.7 \times 0.0205 / 1000 = (3.8335 \times 10^{-4})$

Process mark

1

Moles $\text{Fe}^{2+} = 5 \times 3.8335 \times 10^{-4} = 1.91675 \times 10^{-3}$

Mark for M2 x 5

1

Moles Fe^{2+} in $250 \text{ cm}^3 = 10 \times 1.91675 \times 10^{-3} = 0.0191675$ moles in 50 cm^3

Process mark for moles of iron in titration (M3) x 10

1

Original conc $\text{Fe}^{2+} = 0.0191675 \times 1000 / 50 = 0.383 \text{ mol dm}^{-3}$

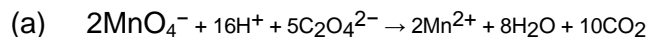
Answer for moles of iron (M4) x 1000 / 50

Answer must be to at least 2 sig. figs. (0.38)

1

[11]

5



1

Mn^{2+} OR Mn^{3+}

If catalyst incorrect can only score M1 and M3

1

(Possible because) Mn can exist in variable oxidation states

1

E_a lowered because oppositely charged ions attract

These marks can be gained in any order

1

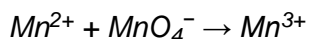
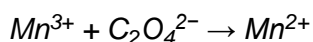
Mn^{3+} (reduced) to Mn^{2+} by $\text{C}_2\text{O}_4^{2-}$ / equation

M5 may appear before M2

1

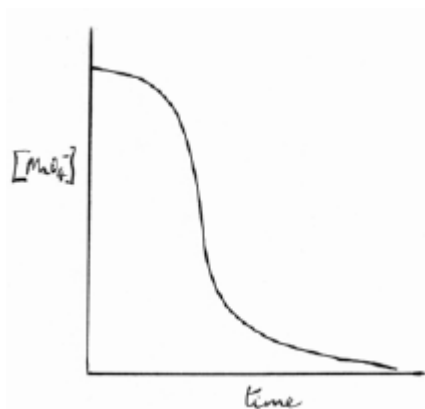
Mn^{2+} (oxidised (back)) to Mn^{3+} by MnO_4^- / equation

M5 and M6 can be scored in unbalanced equations or in words showing:



1

(b) **Graph marks**



S-shaped curve must not rise significantly and must not fall rapidly initially.

Starts on concentration axis **and** is levelling out (can level out on time axis or above but parallel to time axis)

Cannot score graph marks (M1 and M2) if no axes and / or no labels

1

1

Explanation marks

Slope / rate increases as catalyst (concentration) forms

1

Slope / rate decreases as (concentration) of MnO_4^- ions / reactant(s) decreases (OR reactants are being used up)

Explanation marks can be awarded independent of graph.

1

[10]

6

(a) 164.0

Must be 1 decimal place

1

(b) 17.1(%) (= $28.0 \times 100 / Q_a$)

Consequential on their (a)

Ignore precision but must be to at least 2 sig fig.

(i.e. accept 17 or 17.07)

1

(c) (i) Absorption depends on (proportional to) path length / distance travelled through solution

Do not allow size.

1

(ii) To select the colour / frequency / wavelength that is (most strongly) absorbed (by the sample)

Allow the filter is chosen to complement the colour of the solution

1

(iii) Quicker to analyse extracted samples than by titration / uses smaller volumes of solution

1

[5]

7

(a) **Reaction 1**

General principles in marking this question

Square brackets are not essential

Penalise charges on individual ligands rather than on the whole complex

Reagent and species can be extracted from the equation

Ignore conditions such as dilute, concentrated, excess

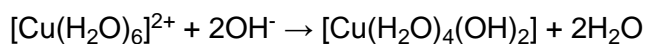
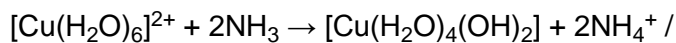
Reagent must be a compound NOT just an ion

Equations must start from $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ except in part (b)

Mark reagent, species and equation independently

ammonia (NH_3) (solution) / NaOH

1



Do not allow OH⁻ for reagent

Product 1, balanced equation 1

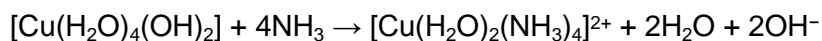
Allow either equation for ammonia

2

(b) **Reaction 2**

Ammonia (conc / xs)

1



Product 1, balanced equation 1

Note that the equation must start from the hydroxide

[Cu(H₂O)₄(OH)₂]

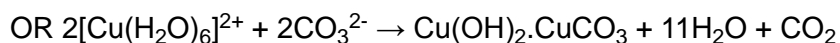
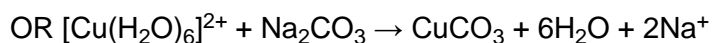
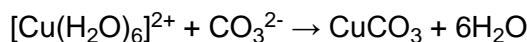
2

(c) **Reaction 3**

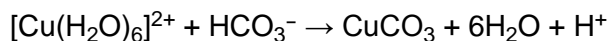
Na₂CO₃ / any identified soluble carbonate / NaHCO₃

Do not allow NaCO₃ or any insoluble carbonate but mark on

1



OR with NaHCO₃



Product 1, balanced equation 1

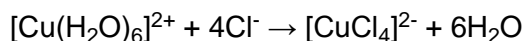
2

(d) **Reaction 4**

HCl (conc / xs) / NaCl

Allow any identified soluble chloride

1



Product 1, balanced equation 1

2

[12]

8

(a) In each of **P** and **Q** the oxidation state of Cr is +3 / both contain Cr³⁺

If oxidation states are different lose M1 and M2

1

In each of **P** and **Q** the electron configuration is the same / $d^3 / 3d^3$

Do not allow just same number of electrons

1

Ligands are different

1

Different energies of (d) electrons / different split of (d) electron energy levels /
different energy gap of (d) electrons / different (d) orbital energy

1

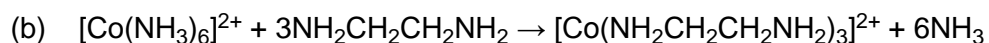
Different wavelengths / frequencies / energies of light / colours (of light) are absorbed
(by the d electrons)

*Reference to emission and / or uv light but not to visible loses M5
and M6*

1

Different wavelengths / frequencies / energies of light / colours (of light) are
transmitted / reflected

1



Allow $\text{NH}_2\text{C}_2\text{H}_4\text{NH}_2$ and $\text{CH}_2\text{NH}_2\text{CH}_2\text{NH}_2$

Allow partial substitution

Do not allow en or other formulae for M1 but can score M2

1

4 particles form 7 particles / increase in number of particles

Allow molecules, entities, ions, moles instead of particles

Do not allow atoms

*Can score M2 if numbers match candidates incorrect equation
provided number of particles increases*

1

disorder / entropy increases / ΔS positive

*Cannot score M3 if number of particles stated or in equation is the
same or decreases*

1

ΔH is approx. zero / no net change in bond enthalpies

Allow same number and type of bonds broken and formed

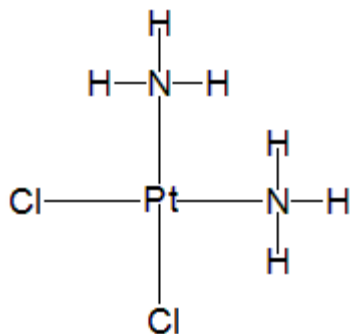
1

ΔG is negative / $\Delta G \leq 0$

Mark M4 and M5 independently

1

(c) (i)



Correct displayed structure

Must show all three N–H bonds on each N

Ignore arrows and lone pairs, attempt to show shape

Ignore charges on atoms in structure for M1

1

Bond angle 90°

Allow 87 to 93 degrees

Allow this angle for any complex with 4 ligands eg if NH₂ or Cl used instead of NH₃

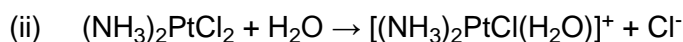
1

Charge of zero

Award this mark if no charge shown on structure but if charges shown on ligands in M1 must state that overall charge = 0

Allow M3 only if cisplatin is correct OR if trans form OR if NH₃ not displayed OR if NH₂ used instead of NH₃

1



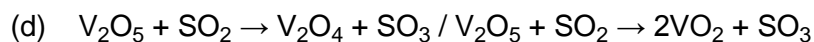
If formula of cisplatin is incorrect, mark consequentially provided H₂O replaces Cl⁻ and charge on complex increases by one

1

(iii) Use in small amounts / short bursts / target the application / monitor the patients

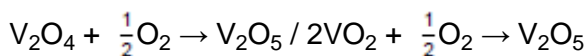
Allow: Give patient time between doses

1



Allow multiples

1



1

Acts as a catalyst / lowers the activation energy

1

Speeds up the (overall) reaction (between SO₂ and oxygen)

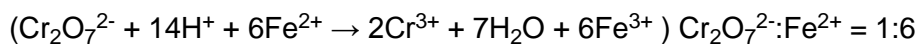
1

[20]

9

- (a) moles of Cr₂O₇²⁻ per titration = $21.3 \times 0.0150 / 1000 = \underline{3.195 \times 10^{-4}}$

1



If 1:6 ratio incorrect cannot score M2 or M3

1

moles of Fe²⁺ = $6 \times 3.195 \times 10^{-4} = 1.917 \times 10^{-3}$

Process mark for M1 × 6 (also score M2)

1

original moles in 250 cm³ = $1.917 \times 10^{-3} \times 10 = 1.917 \times 10^{-2}$

Process mark for M3 × 10

1

mass of FeSO₄·7H₂O = $1.917 \times 10^{-2} \times 277.9 = 5.33$ (g)

Mark for answer to M4 × 277.9

(allow 5.30 to 5.40)

*Answer **must** be to at least 3 sig figs*

Note that an answer of 0.888 scores M1, M4 and M5 (ratio 1:1 used)

1

- (b) (Impurity is a) reducing agent / reacts with dichromate / impurity is a version of FeSO₄ with fewer than 7 waters (not fully hydrated)

Allow a reducing agent or compound that that converts Fe³⁺ into Fe²⁺

1

Such that for a given mass, the impurity would react with more dichromate than a similar mass of FeSO₄·7H₂O

OR for equal masses of the impurity and FeSO₄·7H₂O, the impurity would react with more dichromate.

Must compare mass of impurity with mass of FeSO₄·7H₂O

1

[7]

10

- (a) Negative ions repel one another

1

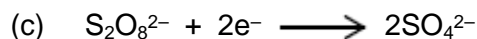
- (b) Positive ions attract negative ions in catalysed process

Allow activation energy decreases.

Allow alternative route with lower E_a

Ignore references to heterogenous catalysis.

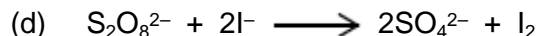
1



Allow multiples including fractions.

Ignore state symbols.

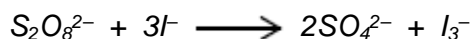
1



Allow multiples including fractions.

Ignore state symbols.

Allow the correct equation involving I_3^-



1

[4]

11

(a) $\Delta E = hv$

Allow = hf

1

$v = \Delta E / h = 2.84 \times 10^{-19} / 6.63 \times 10^{-34} = 4.28 \times 10^{14} \text{ s}^{-1} / \text{Hz}$

Allow $4.3 \times 10^{14} \text{ s}^{-1} / \text{Hz}$

Answer must be in the range:

$4.28 - 4.30 \times 10^{14}$

1

(b) (One colour of) light is absorbed (to excite the electron)

If light emitted, CE = 0

1

The remaining colour / frequency / wavelength / energy is transmitted (through the solution)

Allow light reflected is the colour that we see.

1

(c) Bigger

1

Blue light would be absorbed

OR light that has greater energy than red light would be absorbed

OR higher frequency (of light absorbed / blue light) leads to higher ΔE

Can only score M2 if M1 is correct.

1

(d) Any **three** from:

- (Identity of the) metal
- Charge (on the metal) / oxidation state / charge on complex
- (Identity of the) ligands
- Co-ordination number / number of ligands
- Shape

3 max

[9]

12

- (a) Cobalt has variable oxidation states

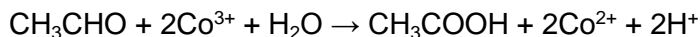
Allow exists as Co(II) and Co(III)

1

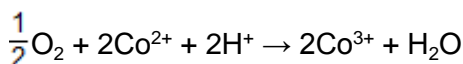
(It can act as an intermediate that) lowers the activation energy

Allow (alternative route with) lower E_a

1

*Allow multiples; allow molecular formulae**Allow equations with H_3O^+*

1



1

- (b) (i)
- $[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 3\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2 \rightarrow [\text{Co}(\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2)_3]^{2+} + 6\text{H}_2\text{O}$

Do not allow en in equation, allow $\text{C}_2\text{H}_8\text{N}_2$

1

The number of particles increases / changes from 4 to 7

*Can score M2 and M3 even if equation incorrect or missing
provided number of particles increases*

1

So the entropy change is positive / disorder increases / entropy increases

1

- (ii) Minimum for
- M1**
- is 3 bidentate ligands bonded to Co

*Ignore all charges for M1 and M3 but penalise charges on any
ligand in M2*

1

Ligands need not have any atoms shown but diagram must show 6 bonds from
ligands to Co, 2 from each ligandMinimum for **M2** is one ligand identified as $\text{H}_2\text{N}-----\text{NH}_2$ *Allow linkage as -C-C- or just a line.*

1

Minimum for **M3** is one bidentate ligand showing two arrows from separate
nitrogens to cobalt

1

- (c) Moles of cobalt =
- $(50 \times 0.203) / 1000 = \underline{0.01015}$
- mol

Allow 0.0101 to 0.0102

1

Moles of AgCl = $4.22/143.4 = 0.0294$

Allow 0.029

*If not AgCl (eg AgCl₂ or AgNO₃), lose this mark and can only score **M1, M4** and **M5***

1

Ratio = Cl⁻ to Co = 2.9 : 1

*Do not allow 3 : 1 if this is the only answer but if 2.9:1 seen somewhere in answer credit this as **M3***

1

[Co(NH₃)₆]Cl₃ (square brackets not essential)

1

Difference due to incomplete oxidation in the preparation

Allow incomplete reaction.

Allow formation [Co(NH₃)₅Cl]Cl₂ etc.

Some chloride ions act as ligands / replace NH₃ in complex.

Do not allow 'impure sample' or reference to practical deficiencies

1

[15]

13

(a) Percentage of oxygen is 42.5% (**M1**)

Allow if shown clearly in the calculation.

1

Co $13.0 / 58.9 = 0.221$, N $18.6 / 14 = 1.329$,

K $25.9 / 39.1 = 0.662$, O $42.5 / 16 = 2.656$ (**M2**)

Allow alternative method if chemically correct.

*If A_r has been divided by the percentage, chemical error, lose **M2** and **M3**.*

1

CoN₆K₃O₁₂ (**M3**)

Allow in any order.

Correct answer without working scores this mark only.

1

(b) Co(NO₂)₆³⁻

Allow a correct diagram bonding through N or O

Do not allow CoN₆O₁₂³⁻

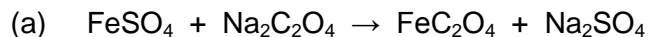
Must have correct overall charge.

Allow consequential answer from part(a) if the charge on the anion is correct.

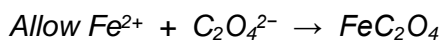
1

[4]

14

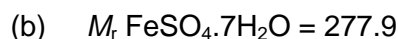


Allow multiples, including fractions.



Allow correct equation which includes water of crystallisation.

1



Allow if shown clearly in the calculation.

Allow 278

1

Moles = $6.95 / 277.9 = 2.5(0) \times 10^{-2}$

Do not penalise precision but must be to a minimum of two significant figures.

Allow correct calculation using incorrect M_r .

Correct answer without working scores this mark only.

1

(c) $3(.00) \times 10^{-2}$

1

(d) Theoretical mass = $2.50 \times 10^{-2} \times 179.8 = 4.50\text{g}$

as long as 2.50×10^{-2} is the smaller of parts (b) and (c) **(M1)**

Allow consequential answer from parts (b) and (c).

Allow theoretical mass = (smaller of parts (b) and (c)) $\times 179.8$

*If larger of parts (b) and (c) used, lose **M1** but can score **M2**.*

Allow answers based on moles of reactant and product.

1

Yield = $3.31 \times 100 / 4.50 = 73.6\%$ **(M2)**

Award this mark only if answer given to 3 significant figures.

Correct answer without working scores this mark only, provided answer given to 3 significant figures.

1

(e) Some left in solution / some lost during filtration

Do not allow 'incomplete reaction'.

Do not allow 'reaction is reversible'.

1

(f) MnO_4^- will oxidise the iron(II) ion and the ethanedioate ion

1

MnO_4^- does not oxidise the Cu^{2+} ion / larger volume needed for iron(II) ethanedioate

1

[9]

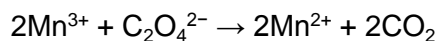
- 15** (a) Water in the gaseous state from the precipitate absorbed by drying agent
OR
Water vapour from the precipitate absorbed by drying agent
Allow 'water vapour reacts with drying agent'.
Do not allow 'absorb water' without qualification. 1
- (b) (Blue to) pink / pink colour observed 1
- 16** (a) Stoppered flask or similar with side arm
Allow gas outlet through stopper. 1
- Calibrated container for collection eg gas syringe
Allow collection over water, but must use calibrated vessel for collection.
Lose 1 mark if apparatus is not gas tight. 1
- (b) Plot a graph of 'volume (of gas)' against 'time' 1
- Determine the slope (gradient) at the beginning 1
- (c) Repeat with same volume **or** concentration of hydrogen peroxide and at the same temperature
Ignore references to results.
Do not allow 'keep everything the same' or words to that effect.
Must mention volume or concentration and temperature. 1
- Add cobalt(II) chloride to one experiment 1
- 17** (a) (i) Two rings only around nitrogen or sulfur
Lose this mark if more than 2 atoms are ringed.
Do not allow two atoms at the same end of the ion. 1
- (ii) 275.8
Accept this answer only. Do not allow 276 1
- (iii) Carboxylate / COO⁻
Allow salt of carboxylic acid or just carboxylic acid. 1
- [2]
- [6]

- (b) $(32.1 / 102.1) = 31.4\%$
Do not penalise precision but do not allow 1 significant figure. 1
- (c) Zineb is mixed with a solvent / water
Max=2 if M1 missed 1
- Use of column / paper / TLC
Lose M1 and M2 for GLC 1
- Appropriate collection of the ETU fraction
OR Appropriate method of detecting ETU
Allow ETU is an early fraction in a column or collecting a range of samples over time, lowest retention time / travels furthest on paper or TLC (allow 1 mark for having the longest retention time in GLC). 1
- Method of identification of ETU (by comparison with standard using chromatography)
If method completely inappropriate, only M1 is accessible 1

[8]

18

- (a) Variable / many oxidation states 1
- (b) $V_2O_5 + SO_2 \rightarrow V_2O_4 + SO_3$
Equations can be in either order
Allow multiples 1
- $V_2O_4 + \frac{1}{2}O_2 \rightarrow V_2O_5$ 1
- (c) (i) In a different phase / state from reactants 1
- (ii) Impurities poison / deactivate the catalyst / block the active sites
Allow (adsorbs onto catalyst AND reduces surface area) 1
- (d) (i) The catalyst is a reaction product 1
- (ii) Mn^{2+} / Mn^{3+} ion(s) 1
- (iii) $4Mn^{2+} + MnO_4^- + 8H^+ \rightarrow 5Mn^{3+} + 4H_2O$
Equations can be in either order 1



1

[9]

19

- (a) A ligand is an electron pair / lone pair donor

Allow uses lone / electron pair to form a co-ordinate bond

1

A bidentate ligand donates two electron pairs (to a transition metal ion) from different atoms / two atoms (on the same molecule / ion)

QoL

1

- (b) CoCl_4^{2-} diagram

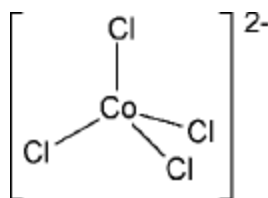
1

Tetrahedral shape

1

$109^\circ 28'$

1



Four chlorines attached to Co with net 2- charge correct

Charge can be placed anywhere, eg on separate formula

Penalise excess charges

Allow 109° to 109.5°

$[\text{Co}(\text{NH}_3)_6]^{2+}$ diagram

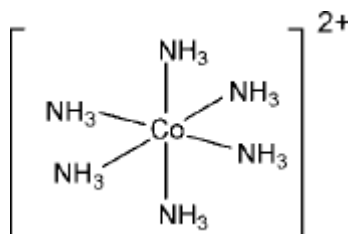
1

Octahedral shape

1

90°

1



Six ammonia / NH_3 molecules attached to Co with 2+ charge correct

Allow 180° if shown clearly on diagram

CE= 0 if wrong complex but mark on if only charge is incorrect

- (c) In different complexes the d orbitals / d electrons (of the cobalt) will have different energies / d orbital splitting will be different

1

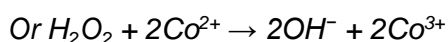
Light / energy is absorbed causing an electron to be excited

1

Different frequency / wavelength / colour of light will be absorbed / transmitted / reflected

1

- (d) 1 mol of H_2O_2 oxidises 2 mol of Co^{2+}



1

$$M_r \text{ CoSO}_4 \cdot 7\text{H}_2\text{O} = 281$$

If M_r wrong, max 3 for M1, M4, M5

1

$$\text{Moles } \text{Co}^{2+} = 9.87 / 281 = 0.03512$$

1

$$\text{Moles } \text{H}_2\text{O}_2 = 0.03512 / 2 = 0.01756$$

M4 is method mark for (M3) / 2 (also scores M1)

1

$$\begin{aligned} \text{Volume } \text{H}_2\text{O}_2 &= (\text{moles} \times 1000) / \text{concentration} \\ &= 0.01756 \times 1000 / 5.00 \end{aligned}$$

$$= 3.51 \text{ cm}^3 / (3.51 \times 10^{-3} \text{ dm}^3)$$

Units essential for answer

M5 is method mark for (M4) x 1000 / 5

Allow 3.4 to 3.6 cm³

If no 2:1 ratio or ratio incorrect Max 3 for M2, M3 & M5

Note: Answer of 7 cm³ scores 3 for M2, M3, M5 (and any other wrong ratio max 3)

Answer of 16.8 cm³ scores 3 for M1, M4, M5 (and any other wrong M_r max 3)

Answer of 33.5 cm³ scores 1 for M5 only (so wrong M_r AND wrong ratio max 1)

1

[16]

20

- (a) Co-ordinate / dative / dative covalent / dative co-ordinate

Do not allow covalent alone

1

- (b) (lone) pair of electrons on oxygen/O

If co-ordination to O^{2-} , CE=0

1

forms co-ordinate bond with Fe / donates electron pair to Fe

'Pair of electrons on O donated to Fe' scores M1 and M2

1

(c) 180° / 180 / 90

Allow any angle between 85 and 95

Do not allow 120 or any other incorrect angle

Ignore units eg °C

1

(d) (i) 3 : 5 / 5 FeC₂O₄ reacts with 3 MnO₄⁻

Can be equation showing correct ratio

1

(ii) **M1** Moles of MnO₄⁻ per titration = $22.35 \times 0.0193/1000 = \underline{4.31 \times 10^{-4}}$

Method marks for each of the next steps (no arithmetic error allowed for M2):

Allow $\underline{4.3 \times 10^{-4}}$ (2 sig figs)

Allow other ratios as follows:

eg from given ratio of 7/3

1

M2 moles of FeC₂O₄ = ratio from (d)(i) used correctly $\times 4.31 \times 10^{-4}$

M2 = $7/3 \times 4.31 \times 10^{-4} = 1.006 \times 10^{-3}$

1

M3 moles of FeC₂O₄ in 250 cm³ = M2 ans $\times 10$

M3 = $1.006 \times 10^{-3} \times 10 = 1.006 \times 10^{-2}$

1

M4 Mass of FeC₂O₄·2H₂O = M3 ans $\times 179.8$

M4 = $1.006 \times 10^{-2} \times 179.8 = 1.81 \text{ g}$

1

M5 % of FeC₂O₄·2H₂O = (M4 ans/1.381) $\times 100$

M5 = $1.81 \times 100/1.381 = 131 \%$ (130 to 132)

1

(OR for M4 max moles of $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O} = 1.381/179.8 (= 7.68 \times 10^{-3})$

for M5 % of $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O} = (\text{M3 ans/above M4ans}) \times 100$

eg using correct ratio 5/3:

Moles of $\text{FeC}_2\text{O}_4 = 5/3 \times 4.31 \times 10^{-4} = 7.19 \times 10^{-4}$

Moles of FeC_2O_4 in $250 \text{ cm}^3 = 7.19 \times 10^{-4} \times 10 = 7.19 \times 10^{-3}$

Mass of $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O} = 7.19 \times 10^{-3} \times 179.8 = 1.29 \text{ g}$

% of $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O} = 1.29 \times 100/1.381 = 93.4$ (allow 92.4 to 94.4)

Note correct answer (92.4 to 94.4) scores 5 marks

Allow consequentially on candidate's ratio

eg **M2** = $5/2 \times 4.31 \times 10^{-4} = 1.078 \times 10^{-3}$

M3 = $1.0078 \times 10^{-3} \times 10 = 1.078 \times 10^{-2}$

M4 = $1.078 \times 10^{-2} \times 179.8 = 1.94 \text{ g}$

M5 = $1.94 \times 100/1.381 = 140 \%$ (139 to 141)

Other ratios give the following final % values

1:1 gives 56.1% (55.6 to 56.6)

5:1 gives 281% (278 to 284)

5:4 gives 70.2% (69.2 to 71.2)

[10]

21

(a) (i) Ammonia

If reagent is missing or incorrect cannot score M3

1

Starts as a pink (solution)

1

Changes to a yellow/straw (solution)

Allow pale brown

Do not allow reference to a precipitate

1

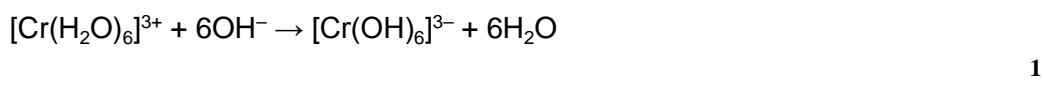
(ii) (dark) brown

Do not allow pale/straw/yellow-brown (i.e. these and other shades except for dark brown)

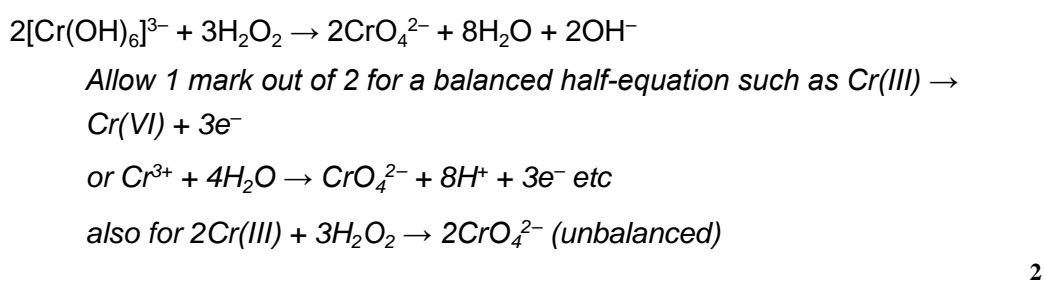
1

(b) (i) Ruby/red-blue/purple/violet/green
Do not allow red or blue
If ppt mentioned contradiction/CE =0 1

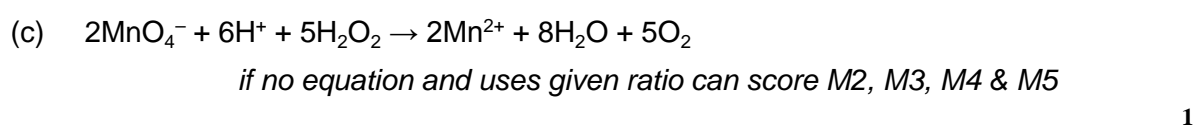
Green
If ppt mentioned contradiction/CE =0 1



Formula of product
Can score this mark in (b) (ii) 1



Yellow
Do not allow orange 1



Moles $\text{MnO}_4^- = (24.35/1000) \times 0.0187 = \underline{4.55 \times 10^{-4}}$
Note value must be quoted to at least 3 sig. figs.
M2 is for 4.55×10^{-4} 1

Moles $\text{H}_2\text{O}_2 = (4.55 \times 10^{-4}) \times \underline{5/2} = 1.138 \times 10^{-3}$
M3 is for $\times 5/2$ (or $7/3$)
Mark consequential on molar ratio from candidate's equation 1

Moles H₂O₂ in 5 cm³ original

M4 is for $\times 10$

1

$$= (1.138 \times 10^{-3}) \times 10 = 0.01138$$

$$\text{Original } [\text{H}_2\text{O}_2] = 0.01138 \times (1000/5) = 2.28 \text{ mol dm}^{-3}$$

(allow 2.25-2.30)

M5 is for consequentially correct answer from (answer to mark 4) \times (1000/5)

Note an answer of between 2.25 and 2.30 is worth 4 marks)

If candidate uses given ratio 3/7 max 4 marks:

M1: Moles of MnO₄⁻ = 4.55×10^{-4}

M2: Moles H₂O₂ = $(4.55 \times 10^{-4}) \times 7/3 = 1.0617 \times 10^{-3}$

M3: Moles H₂O₂ in 5 cm³ original

$$= (1.0617 \times 10^{-3}) \times 10 = 0.01062$$

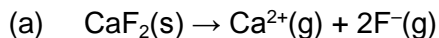
M4: Original [H₂O₂] = $0.01062 \times (1000/5) = 2.12 \text{ mol dm}^{-3}$

(allow 2.10 to 2.15)

1

[17]

22



1

(b) (i) Enthalpy change for formation of 1 mol of substance

Allow heat energy change, NOT energy

1

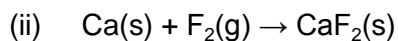
From its elements

1

Reactants and products/all substances in their standard states

Or normal states at 298 K, 1 bar (100 kPa)

1



1

(iii) $\Delta H_f(\text{CaF}_2) = \Delta H_a(\text{Ca}) + 1\text{st IE}(\text{Ca}) + 2^{\text{nd}} \text{IE}(\text{Ca}) + \text{BE}(\text{F}_2) + 2 \times \text{EA}(\text{F}) - \Delta H_L(\text{CaF}_2)$

Or labelled diagram

1

$$= 193 + 590 + 1150 + 158 + (2 \times -348) - 2602$$

1

$$= -1207 \text{ kJ mol}^{-1}$$

Correct answer scores 3

-842 scores 2 (transfer error)

-859 scores 1 only (using one E.A.)

Units not required, wrong units lose 1 mark

1

- (c) Electrostatic attraction stronger/ionic bonding stronger/attraction between ions stronger/more energy to separate ions

Molecular attraction/atoms/intermolecular forces CE=0

1

Because fluoride (ion) smaller than chloride

Do not allow F or fluorine

1

(d) (i) $\Delta H = \Delta H_L + \Sigma \Delta H_{\text{hyd}} = 2237 - 1650 + (2 \times -364)$

Can be on cycle/diagram

1

$$= -141 \text{ kJ mol}^{-1}$$

Correct answer scores 2

Units not required, wrong units lose 1 mark

1

- (ii) Decreases

If ans to (d)(i) positive allow increases

1

Reaction exothermic/ ΔH -ve

If (d)(i) +ve allow endothermic/ ΔH + ve

1

(Equilibrium) shifts to left/backwards

(as temperature rises)/equilibrium

opposes the change

If (d) (i) +ve allow shifts to right/forwards/equilibrium opposes the change

If no answer to (d) (i) assume -ve ΔH used

If effect deduced incorrectly from any ΔH CE = 0 for these 3 marks

1

- (e) u.v. absorbed: electrons/they move to higher energy (levels)/electrons excited 1

visible light given out: electrons/they fall back down/move to lower energy (levels)

Must refer to absorbing u.v. NOT visible light or this must be implied.

1

[17]

23

- (a) Same phase/state 1

- (b) Because only exist in one oxidation state
Allow do not have variable oxidation states 1

- (c) $2\text{I}^- + \text{S}_2\text{O}_8^{2-} \rightarrow \text{I}_2 + 2\text{SO}_4^{2-}$
Ignore state symbols
Allow multiples 1

- (d) Both (ions) have a negative charge
Or both have the same charge
Or (ions) repel each other
Do not allow both molecules have the same charge (contradiction) 1

- (e) $2\text{Fe}^{2+} + \text{S}_2\text{O}_8^{2-} \rightarrow 2\text{Fe}^{3+} + 2\text{SO}_4^{2-}$ 1



Equations can be in any order

Positive and negative (ions)/oppositely charged (ions)
Mark independently 1

- (f) Equations 1 and 2 can occur in any order
Allow idea of Fe^{3+} converted to Fe^{2+} then Fe^{2+} converted back to Fe^{3+} 1

[8]

24

- (a) Partially filled/incomplete d sub-shell/orbital/shell

Ignore reference to f orbitals

Do not allow d block

Do not allow half-filled d orbitals

1

- (b) Has ligand(s)

Allow molecules/ions with lone pairs

1

linked by co-ordinate bonds

Allow dative/donation of lone pair

1

- (c) (Blue) light is absorbed (from incident white light)

1

Due to electrons moving to higher levels/electrons excited

Allow $d \rightarrow d$ transitions

1

Red light (that) remains (is transmitted)/light that remains (transmitted light) is the colour observed

Allow red light reflected

1

- (d) (i) Circle round any O^-

List principle

1

Circle round either N

1

- (ii) $EDTA^{4-} + [Co(H_2O)_6]^{2+} \rightarrow [CoEDTA]^{2-} + 6H_2O$

Allow missing square brackets

Ignore state symbols

1

- (iii) Increase in entropy/ ΔS positive

Or increase in disorder

1

Because 2 mol (of particles/molecules/species/entities) form 7 mol

Allow 'increase in number' as stated in words or as shown by any numbers deduced correctly from an incorrect equation

Do not allow increase in ions/atoms

1

- (e) (i) Co-ordinate/dative/dative covalent bond
Allow pair of electrons donated by nitrogen/ligand
Do not allow pair of electrons donated from Iron/Fe 1
- Covalent bond
Shared electron pair 1
- (ii) Transport of oxygen/O₂
Allow any statement that implies oxygen carried (around the body)
Do not allow transport of carbon dioxide (CO₂). This also contradicts the mark (list principle) 1
- (iii) Because it bonds to the iron/haemoglobin
Allow blocks site
/CO has greater affinity for haemoglobin
/carboxyhaemoglobin more stable than oxyhaemoglobin 1
- Displaces oxygen
Or prevents transport of oxygen
QoL 1

[16]

25

- (a) W is CuCl₄²⁻ 1
- Yellow-green/yellow/green
Not necessary to indicate solution
Do not allow precipitate/solid 1
- $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 4\text{Cl}^- \rightarrow \text{CuCl}_4^{2-} + 6\text{H}_2\text{O}$
Allow + 4HCl → 4H⁺ 1

- (b) X is $\text{Cu}(\text{H}_2\text{O})_4(\text{OH})_2$
 Allow $\text{Cu}(\text{OH})_2$ /copper hydroxide 1
- Blue precipitate/solid
 Ignore shades 1
- $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 2\text{NH}_3 \rightarrow \text{Cu}(\text{H}_2\text{O})_4(\text{OH})_2 + 2\text{NH}_4^+$
 Allow any balanced equation/equations leading to this hydroxide or $\text{Cu}(\text{OH})_2$
 But must use ammonia 1
- (c) Y is $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ 1
- Deep/dark/royal blue solution
 QoL 1
- $\text{Cu}(\text{H}_2\text{O})_4(\text{OH})_2 + 4\text{NH}_3 \rightarrow [\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+} + 2\text{H}_2\text{O} + 2\text{OH}^-$
 Accept equation for formation from $\text{Cu}(\text{OH})_2$ 1
- (d) Z is CuCO_3
 Allow copper carbonate 1
- Green solid/precipitate
 Allow blue-green precipitate 1
- $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + \text{CO}_3^{2-} \rightarrow \text{CuCO}_3 + 6\text{H}_2\text{O}$ 1
- (e) (i) $\text{Cu}^{2+}(\text{aq}) + \text{Fe}(\text{s}) \rightarrow \text{Cu}(\text{s}) + \text{Fe}^{2+}(\text{aq})$
 Allow hydrated ions
 State symbols not essential but penalise if wrong 1
- Blue
 Do not allow description of solids 1
- Green
 Allow yellow/(red-)brown/orange 1

- (ii) Any two correct points about copper extraction from two of these three categories:

Any relevant mention of lower energy consumption

Do not allow reference to electricity alone or to temperature alone.

Any relevant mention of benefits of less mining (of copper ore)

Allow avoids depletion of (copper ore) resources

Less release of CO₂ (or CO) into the atmosphere

Not just greenhouse gases. Must mention CO₂ or CO

Max 2

[17]

26

- (a) FeCl₃ accepts electron pairs from water

1

Hence acts as a Lewis acid

1

[Fe(H₂O)₆]³⁺ donates protons

1

Hence acts as a Bronsted-Lowry acid

1

- (b) The Fe²⁺ ion has a smaller charge to size ratio

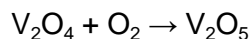
1

Hence less polarising than Fe³⁺ or less weakening effect on O-H bonds

1

- (c) (i) $V_2O_5 + SO_2 \rightarrow V_2O_4 + SO_3$

1



1

(ii) Both ions are negative or ions repel 1



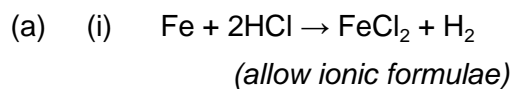
Balanced 1



Balanced 1

[13]

27



(ii) $PV = nRT$ $n = PV/RT$
(allow either formula but penalise contradiction) 1

$$n = \frac{110000 \times 102 \times 10^{-6}}{8.31 \times 298}$$
 1

$= 4.53 \times 10^{-3}$ (mol)
(answer must have at least 3 sig. figs. Ignore units) 1

(iii) Moles of iron = $4.5(3) \times 10^{-3}$ mol

(allow conseq on (a)(ii))

(or = $4.2(5) \times 10^{-3}$ if candidate uses given moles of hydrogen)

1

Mass of iron = $4.53 \times 10^{-3} \times 55.8 = 0.253$ g

(mark is for method mass = moles $\times A_r$)

(Mass of iron can be 56)

1

(iv) $0.253 \times 100/0.263 = 96.1$ % (mark is for answer to 2 sig. figs.)

(allow conseq on mass of iron. E.g. = 90% from

$4.2(5) \times 10^{-3}$ moles of H_2 and Fe)

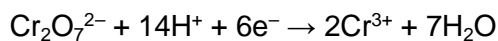
(Do not allow answers greater than or equal to 100%)

1

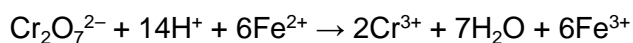
(b) (i) $Fe^{2+} \rightarrow Fe^{3+} + e^-$

(ignore state symbols)

1



1



1

(ii) Moles of dichromate = moles $Fe^{2+}/6$

= $4.53 \times 10^{-3}/6 = 7.55 \times 10^{-4}$

(Allow conseq, mark is for method (a)(iii)/6)

1

Volume of dichromate = moles/concentration

(= $(7.55 \times 10^{-4} \times 1000)/0.0200$)

(mark is for this method)

1

$$V = 37.75 \text{ (cm}^3\text{)}$$

(allow 37.7 to 37.8, allow no units but penalise wrong units)

(allow conseq on moles of dichromate)

(if value of 3.63×10^{-3} used answer is 30.2 to 30.3,

otherwise ans = moles $\text{Fe}^{2+}/0.00012$)

*(if mole ratio wrong and candidate does not divide by 6,
max score is ONE for volume method)*

1

(iii) (KMnO_4) will also oxidise (or react with) Cl^- (or chloride or HCl)

1

[14]

28

[1]

29

(a) oxidation state of N in $\text{Cu}(\text{NO}_3)_2$: +5;

1

oxidation state of N in NO_2 : +4;

1

oxidation product: oxygen;

1

(b) copper-containing species: $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$;

1

shape: octahedral;

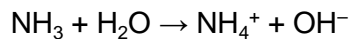
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(c) (i) precipitate B: $\text{Cu}(\text{H}_2\text{O})_4(\text{OH})_2$ or $\text{Cu}(\text{OH})_2$ or name;

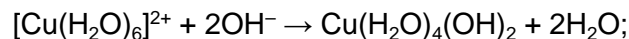
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equation: $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 2\text{NH}_3 \rightarrow \text{Cu}(\text{H}_2\text{O})_4(\text{OH})_2 + 2\text{NH}_4^+$

OR



and



1

(ii) NH_3 accepts a proton;

1

- (d) (i) identity: $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$; 1
- colour: deep blue; 1
- equation: 1
- $$\text{Cu}(\text{H}_2\text{O})_4(\text{OH})_2 + 4\text{NH}_3 \rightarrow [\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+} + 2\text{H}_2\text{O} + 2\text{OH}^-;$$
- (ii) NH_3 is an electron pair donor; 1
- (e) identity: $[\text{CuCl}_4]^{2-}$; 1
- colour: yellow-green; 1
- shape: tetrahedral; 1
- (f) (i) $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10}$; 1
- (ii) role of Cu: a reducing agent; 1

[17]

30

- (a) most powerful reducing agent: Zn; 1
- (b) (i) reducing species: Fe^{2+} 1
- (ii) oxidising species: Cl_2 ; 1
- (c) (i) standard electrode potential 1.25 V; 1
- (ii) equation: $\text{Ti}^{3+} + 2 \text{Fe}^{2+} \rightarrow 2\text{Fe}^{3+} + \text{Ti}$ + balanced; 1
- correct direction; 1

(d) (i) moles $\text{KMnO}_4 = 16.2 \times 0.0200 \times 10^{-3} = 3.24 \times 10^{-4}$; 1

moles $\text{H}_2\text{O}_2 = \text{Moles KMnO}_4 \times 5 / 2 = 8.10 \times 10^{-4}$; 1

8.10×10^{-4} moles H_2O_2 in 25 cm^3
 $8.10 \times 10^{-4} \times 1000 / 25$ in $1000 \text{ cm}^3 = 0.0324 \text{ mol dm}^{-3}$; 1

hence $\text{g dm}^{-3} = \text{mol dm}^{-3} \times M_r = 0.0324 \times 34 = 1.10$;
(penalise use of an incorrect H_2O_2 to KMnO_4 ratio by two marks) 1

(ii) $PV = nRT$; 1

hence $V = nRT / P$
 $= 8.10 \times 10^{-4} \times 8.31 \times 298 / 98000$; 1

$= 2.05 \times 10^{-5}$; 1

units m^3 ;
(mark consequentially to answers in (c)(i))
(allow correct answers with other units)
(answers to (c)(i) and (ii) must be to 3 significant figures; penalise once only) 1

[14]

31

(a) effect on reaction rate: catalyst provides an alternative reaction route.; 1

with a lower E_a ; 1

more molecules able to react or rate increased; 1

equilibrium: forward and backward rates changes by the same amount; 1

hence concentration of reactants and products constant or yield unchanged; 1

- (b) heterogeneous: catalyst in a different phase or state to that of the reactants; 1
- active site: place where reactants adsorbed or attached or bond etc.; 1
- reaction occurs or an explanation of what happens;
(allow absorbed) 1
- reasons: large surface area;
reduce cost or amount of catalyst; 2
- catalyst poison: lead adsorbed;
lead not desorbed or site blocked;
(lead adsorbed irreversibly scores both of these marks) 2

- (c) reaction slow as: both ions negatively charged or ions repel; 1
- $2\text{Fe}^{2+} + \text{S}_2\text{O}_8^{2-} \rightarrow 2\text{Fe}^{3+} + 2\text{SO}_4^{2-}$ Species;
Balanced; 2
- $2\text{Fe}^{3+} + 2\text{I}^- \rightarrow 2\text{Fe}^{2+} + \text{I}_2$ Species ;
Balanced; 2

[17]

32

- (a) Ligand: -
atom, ion or molecules which can donate a pair of electrons to a metal ion. 1
- co-ordinate bond:- a covalent bond 1
- in which both electrons are donate by one atom 1

(b) (i)	Two correct complex ions	1
	Balanced equation	1
	Two correct colours	2
(ii)	Complex with a bidentate ligand	1
	Balanced equation	
	<i>NB en not allowed as a ligand unless structure also given</i>	1
	More molecules/ions formed	1
	Increase in entropy	1
	more stable complex formed	1
		Max 2
(c)	ΔE ; energy absorbed by electron, ground to excited state (QoL)	1
	h ; Planck's constant or a constant	1
	Change in	
	Oxidation state	1
	Ligand	1
	Co-ordination number	
	<i>Apply list principle to incorrect additional answers</i>	1

[16]

33	(a) Iron		1	
	Heterogeneous; catalyst in a different phase from that of the reactants		1	
	Poison; a sulphur compound (allow sulphur)		1	
	Poison strongly adsorbed onto active sites/ blocked		1	
	Poison not desorbed or reactants not adsorbed or catalyst surface area reduced		1	
	(b) Pale green solution	1		
	Green precipitate formed		1	
	Insoluble in excess ammonia		1	
	Equation:			
	e.g. $[\text{Fe}(\text{H}_2\text{O})_6]^{2+} + 2\text{NH}_3 \rightarrow [\text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2] + 2\text{NH}_4^+$ Species		1	
	Balance		1	
	<i>NB Allow equations with H₂O and OH⁻ if reaction of H₂O with NH₃ also given</i>			
			Max 4	[9]

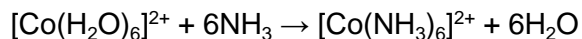
A 34		[1]
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D 35		[1]
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36

- (a) (i) An atom, ion or molecule which can donate a lone electron pair 1
- (ii) A central metal ion/species surrounded by co-ordinately bonded ligands or ion in which co-ordination number exceeds oxidation state 1
- (iii) The number of co-ordinate bonds formed to a central metal ion or number of electron pairs donated or donor atoms 1

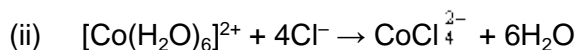
(b) (i) *Allow the reverse of each substitution*



Complex ions 1

Balanced 1

Allow partial substitution

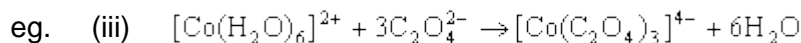


Complex ions 1

Balanced

or H₂O or NH₃ or C₂O₄²⁻ by Cl⁻

1



Complex ions 1

Balanced 1

Allow all substitution except

(i) NH₃ by H₂O

(ii) more than 2Cl⁻ substituted for NH₃ or H₂O



Complex ions 1

Balanced

or H₂O or NH₃ by C₂O₄²⁻ and NH₃ or Cl⁻ by EDTA⁴⁻

1

- (c) (i) $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$ 1
- (ii) $\text{Fe}(\text{OH})_2$ or $\text{Fe}(\text{OH})_2(\text{H}_2\text{O})_x$ where $x = 0$ to 4 1
- (iii) Fe^{2+} is oxidised to Fe^{3+} or $\text{Fe}(\text{OH})_3$ 1
- By oxygen in the air 1

[15]