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

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

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

....

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

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....

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

Moles of iron ....

Mass of iron ....

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

....

....

(7)

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

Half-equation for the oxidation of Fe²⁺

....

Half-equation for the reduction of Cr₂O₇²⁻

....

Overall equation

....

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

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

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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).

....

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(7)
(Total 14 marks)

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

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(5)

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

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

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

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

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(3)

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

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

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(2)

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

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(5)
(Total 15 marks)

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

Cobalt-containing species ....

Precipitate M ....

(2)

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

....

(1)

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

Type of reaction ....

Reactant responsible ....

(2)

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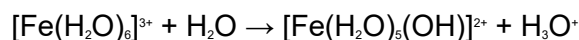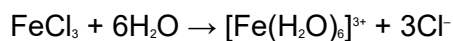
Identify **R** and explain its formation.

Identity of R ....

Explanation ....

(2)
(Total 7 marks)

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

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

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

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

(4)

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

(2)

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

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

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

(7)
(Total 13 marks)

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

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

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

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

....

(1)

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

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(1)

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

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(5)

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

....

(1)

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

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(1)
(Total 9 marks)