Q1. A green solution, **X**, is thought to contain $[Fe(H_2O)_6]^{2+}$ ions.

(a) The presence of these ions can be confirmed by reacting separate samples of solution **X** with aqueous ammonia and with aqueous sodium carbonate.

Write equations for each of these reactions and describe what you would observe.

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(4)

(b) A 50.0 cm^3 sample of solution **X** was added to 50 cm^3 of dilute sulfuric acid and made up to 250 cm^3 of solution in a volumetric flask.

A 25.0 cm^3 sample of this solution from the volumetric flask was titrated with a 0.0205 mol dm^{-3} solution of $KMnO_4$
At the end point of the reaction, the volume of $KMnO_4$ solution added was 18.70 cm^3.

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

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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)

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

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

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

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

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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)

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

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

$2CH_3CHO + O_2 \longrightarrow 2CH_3COOH$

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

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

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

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

(i) Write an equation for this reaction.

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

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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 cm^3 of 0.203 mol dm^{-3} aqueous cobalt(II) chloride with ammonia and an oxidising agent followed by hydrochloric acid.

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

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

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

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

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(5)
(Total 15 marks)

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

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

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

(a) Which element is calcium?

X ⬭

Y ⬭

Z ⬭

(1)

(b) Which element is vanadium?

X ⬭

Y ⬭

Z ⬭

(1)

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

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

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

Oxidation state = ...

(6)
(Total 11 marks)

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

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

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

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

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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)

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

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

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

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

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(2)
(Total 7 marks)