## Q1.

This question is about iron and its ions.

(a) Discuss the role of iron as a heterogeneous catalyst in the Haber process.

$$3\ H_2 + N_2 \rightleftharpoons 2\ NH_3$$

Your answer should include:

- the meaning of the term heterogeneous catalyst
- how iron acts as a heterogeneous catalyst
- the factors that affect the efficiency and lifetime of the catalyst.

**(6)**

(b) $Fe^{2+}$ ions catalyse the reaction between peroxodisulfate(VI) ions and iodide ions in aqueous solution.

$$S_2O_8^{2-}(aq) + 2\ I^-(aq) \rightarrow 2\ SO_4^{2-}(aq) + I_2(aq)$$

Explain why this reaction is slow before the catalyst is added.
Give **two** equations to show how $Fe^{2+}$ ions catalyse this reaction.

Why reaction is slow before catalyst added _____

_____

Equation 1

_____

Equation 2

_____

**(4)**

(c) Give a reason why $Zn^{2+}$ ions do **not** catalyse the reaction in part (b).

_____

_____

**(1)**

(d) Iron reacts with dilute hydrochloric acid to form iron(II) chloride and hydrogen.

$$Fe(s) + 2\ HCl(aq) \rightarrow FeCl_2(aq) + H_2(g)$$

A 0.998 g sample of pure iron is added to 30.0 $cm^3$ of 1.00 mol $dm^{-3}$ hydrochloric acid.

One of these reagents is in excess and the other reagent limits the amount of hydrogen produced in the reaction.

Calculate the maximum volume, in $m^3$, of hydrogen gas produced at 30 $^oC$ and 100 kPa.

Give your answer to 3 significant figures.

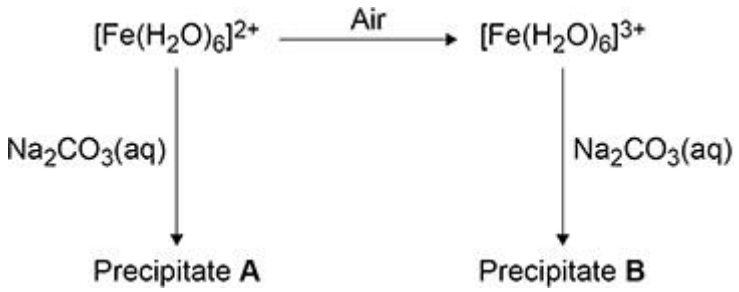
In your answer you should identify the limiting reagent in the reaction.

The gas constant, $R$ = 8.31 J $K^{-1}$ $mol^{-1}$

Volume of hydrogen _____ $m^3$

**(6)**

The figure below shows some reactions of iron ions in aqueous solution.




(e) Identify **A** and state its colour.

Identity _____

Colour _____

**(2)**

(f) Give the formula of **B** and state its colour.

Give an ionic equation for the reaction of $[Fe(H_2O)_6]^{3+}$ with aqueous $Na_2CO_3$ to form **B**.

Formula _____

Colour _____

Ionic equation

_____

**(3)**

(g) Explain why an aqueous solution containing $[Fe(H_2O)_6]^{3+}$ ions has a lower pH than an aqueous solution containing $[Fe(H_2O)_6]^{2+}$ ions.

_____

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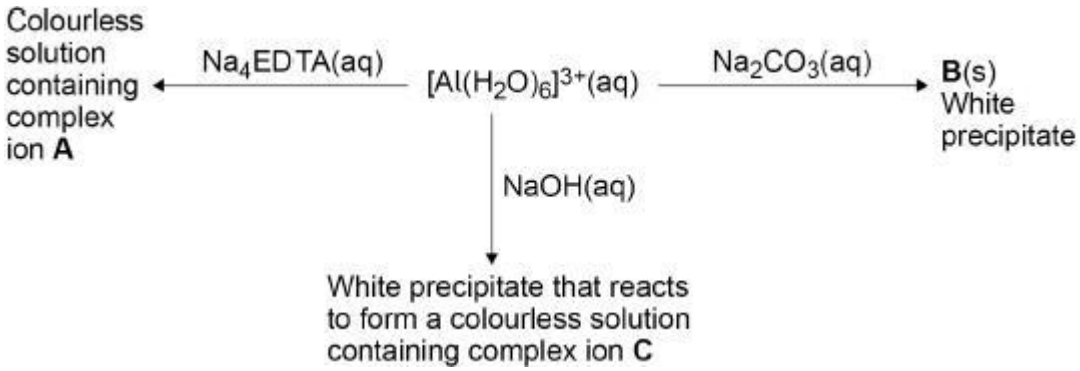
**(3)**

**(Total 25 marks)**

## Q2.

Some reactions of the $[Al(H_2O)_6]^{3+}(aq)$ ion are shown.




(a) Give the formula of the white precipitate **B**.

State **one** other observation when $Na_2CO_3(aq)$ is added to a solution containing $[Al(H_2O)_6]^{3+}(aq)$ ions.

Give an equation for this reaction.

Formula of **B**

_____

Observation

_____

Equation

_____

**(3)**

(b) Give the formula of the complex ion **C**.

State **one** condition needed for the formation of **C** from $[Al(H_2O)_6]^{3+}(aq)$ and NaOH(aq).

Give an equation for this reaction.

Formula of **C**

_____

Condition

_____

Equation

_____

**(3)**

(c) Deduce the formula of the complex ion **A**.

_____

**(1)**

(d) Explain, with the use of an equation, why a solution containing $[Al(H_2O)_6]^{3+}$ has a pH <7

Equation

_____

Explanation

_____

_____

_____

_____

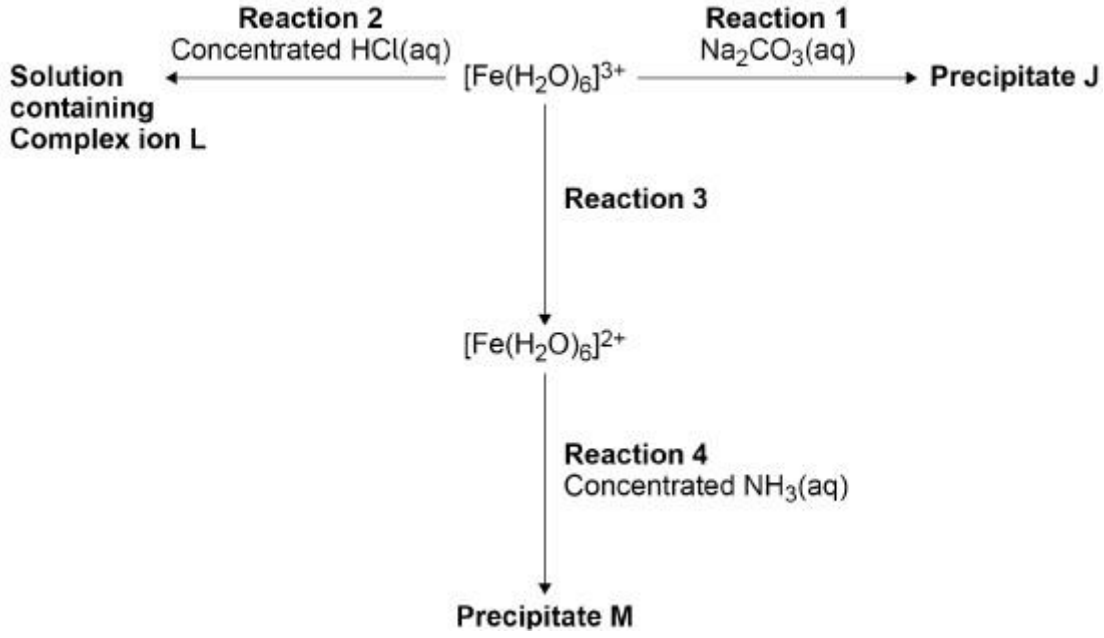
_____

**(3)**

**(Total 10 marks)**

## Q3.

The diagram shows some reactions of aqueous iron ions.




(a) Give the formula of **Precipitate J** and state its colour.

Give an equation for **Reaction 1**.
Formula of **J**

_____

Colour

_____

Equation

_____

**(3)**

(b) Give the formula of **L** and an equation for **Reaction 2**.

Formula of **L**

_____

Equation

_____

**(2)**

(c) Suggest a reagent for **Reaction 3**.

_____

**(1)**

(d) Give the formula of **Precipitate M** and state its colour.

Formula of **M**

_____

Colour

_____

**(2)**

(e) Transition metal complexes have different shapes and many show isomerism.

Describe the different shapes of complexes and show how they lead to different types of isomerism.
Use examples of complexes of cobalt(II) and platinum(II).

You should draw the structures of the examples chosen.

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_____

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**(6)**

**(Total 14 marks)**

## Q4.

(a) When anhydrous aluminium chloride reacts with water, solution **Y** is formed that contains a complex aluminium ion, **Z**, and chloride ions.

Give an equation for this reaction.

_____

**(1)**

(b) Give an equation to show how the complex ion **Z** can act as a Brønsted–Lowry acid with water.

_____

**(1)**

(c) Describe **two** observations you would make when an excess of sodium carbonate solution is added to solution **Y**.

Give an equation for the reaction. In your equation, include the formula of each complex aluminium species.

Observation 1

_____

_____

Observation 2

_____

_____

Equation

_____

**(3)**

(d) Aqueous potassium hydroxide is added, until in excess, to solution **Y**.

Describe **two** observations you would make.
For each observation give an equation for the reaction that occurs.
In your equations, include the formula of each complex aluminium species.

Observation 1

_____

_____

Equation 1

_____

Observation 2

_____

_____

Equation 2

_____

**(4)**

**(Total 9 marks)**

## Q5.

The following tests were carried out to identify an unknown green salt **Y**.

An aqueous solution of **Y** gave a cream precipitate of compound **A** when reacted with silver nitrate solution.

Compound **A** gave a colourless solution when reacted with concentrated ammonia solution.

Another aqueous solution of **Y** gave a green precipitate **B** when reacted with sodium carbonate solution.

The green precipitate **B** was filtered and dried and then reacted with sulfuric acid to give a pale green solution containing compound **C** and a colourless gas **D**.

(a) Identify by name or formula the compounds **A**, **B**, **C**, **D** and **Y**.

Identity of **A**

_____

Identity of **B**

_____

Identity of **C**

_____

Identity of **D**

_____

Identity of **Y**

_____

**(5)**

(b) Write the simplest ionic equation for the reaction of silver nitrate solution with the anion that is present in compound **Y**.

_____

**(1)**

(c) Write the simplest ionic equation for the reaction that occurs between the green precipitate **B** and sulfuric acid.

_____

**(1)**

**(Total 7 marks)**

## Q6.

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

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

Write an equation for this reaction.

_____

**(1)**

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

_____

_____

_____

_____

_____

**(2)**

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

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

**(2)**

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

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

Tick (✓) **one** box.

change in entropy is negative ☐

change in entropy is close to zero ☐

change in entropy is positive ☐

**(1)**

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

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

_____

**(1)**

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

Calculate the percentage of iron in the sample of iron tablets.

Give your answer to the appropriate number of significant figures.

Percentage _____ %

**(4)**

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

_____

**(1)**

**(Total 12 marks)**

## Q7.

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

Explain how this co-ordinate bond is formed.

_____

_____

_____

_____

_____

**(2)**

(b) Describe what you would observe when dilute aqueous ammonia is added dropwise, to excess, to an aqueous solution containing copper(II) ions. Write equations for the reactions that occur.

_____

_____

_____

_____

_____

_____

_____

**(4)**

(c) When the complex ion $[Cu(NH_3)_4(H_2O)_2]^{2+}$ reacts with 1,2-diaminoethane, the ammonia molecules but not the water molecules are replaced.

Write an equation for this reaction.

**(1)**

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

**(2)**

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

**(2)**

**(Total 11 marks)**

## Q8.

What forms when a solution of sodium carbonate is added to a solution of gallium(III) nitrate?

**A** A white precipitate of gallium(III) carbonate. ⬭

**B** A white precipitate of gallium(III) hydroxide. ⬭

**C** A white precipitate of gallium(III) carbonate and bubbles of carbon dioxide. ⬭

**D** A white precipitate of gallium(III) hydroxide and bubbles of carbon dioxide. ⬭

**(Total 1 mark)**

## Q9.

Which compound gives a colourless solution when an excess of dilute aqueous ammonia is added?

**A** $MgCl_2$ ⬭

**B** $AgCl$ ⬭

**C** $CuCl_2$ ⬭

**D** $AlCl_3$ ⬭

**(Total 1 mark)**

## Q10.

What is the final species produced when an excess of aqueous ammonia is added to aqueous aluminium chloride?

**A** $[Al(NH_3)_6]^{3+}$ ⬭

**B** $[Al(OH)_3(H_2O)_3]$ ⬭

**C** $[Al(OH)_4(H_2O)_2]^-$ ⬭

**D** $[Al(OH)(H_2O)_5]^{2+}$ ⬭

**(Total 1 mark)**

## Q11.

Corrosion can be defined as the degradation of a material when it comes into contact with the environment. For iron, this process is called rusting.

(a) When iron rusts it reacts with oxygen and water vapour in the air initially to form a brown, flaky solid that can be regarded as iron(III) hydroxide

Write an equation, including state symbols, for the overall reaction of the iron with oxygen and water vapour to form iron(III) hydroxide.

_____

**(2)**

(b) Explain why this type of corrosion is not seen on aluminium structures that have been exposed to the environment for a similar time as iron structures.

_____

_____

_____

**(2)**

**(Total 4 marks)**