# F325: Equilibria, Energetics and Elements
# 5.3.1 Transition Metals

231 marks

**1.** This question looks at the chemistry of transition elements.

(a) (i) Explain what is meant by the terms *transition element*, *complex ion* and *ligand*,

(ii) Discuss, with examples, equations and observations, the typical reactions of transition elements.

In your answer you should make clear how any observations provide evidence for the type of reaction discussed.

[11]

(b) Describe, using suitable examples and diagrams, the different shapes and stereoisomerism shown by complex ions.

In your answer you should make clear how your diagrams illustrate the type of stereoisomerism involved.

[9]

[Total 20 marks]

**2.** Mercury thermometers are not used in some laboratories because of the danger of mercury vapour. This vapour is very easily absorbed through the lungs into the blood.

In the blood, mercury reacts with hydrogen peroxide to form mercury(II) oxide.

$$Hg + H_2O_2 \rightarrow HgO + H_2O$$

The mercury(II) oxide formed accumulates within organs in the body.

Use oxidation numbers to show that the reaction between mercury and hydrogen peroxide is an example of both oxidation and reduction.

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.....

.....

[Total 2 marks]

**3.** Mercury forms two ions, $Hg_2^{2+}$ and $Hg^{2+}$. The table shows the electronic configuration of mercury in these ions.

| ion | electronic configuration |
|---|---|
| $Hg_2^{2+}$ | $[Xe]4f^{14}5d^{10}6s^1$ |
| $Hg^{2+}$ | $[Xe]4f^{14}5d^{10}$ |

Use the electronic configurations to explain why mercury is **not** a transition element.

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.....

[Total 1 mark]

**4.** A sample of iron is heated with a stream of dry hydrogen chloride. A different chloride of iron is formed that contains the $Fe^{2+}$ ion. This chloride dissolves in water to form a pale green solution that contains the hexaaquairon(II) complex ion.

(i) Complete the electronic configuration of $Fe^{2+}$.

$1s^2 2s^2 2p^6$ .....

[1]

(ii) Draw the shape of the hexaaquairon(II) complex ion. Include the bond angles on your diagram.

[2]

(iii) Aqueous sodium hydroxide is added to a solution containing $Fe^{2+}(aq)$.

State what you would observe.

.....

Write an ionic equation, with state symbols, for the reaction.

.....

[2]

[Total 5 marks]

**5.** The percentage purity of a sample of manganese(IV) oxide, $MnO_2$, can be determined by its reaction with acidified iron(II) ions.

- Stage 1 – A sample of known mass of the impure $MnO_2$ is added to a conical flask.
- Stage 2 – The sample is reacted with a known excess amount of $Fe^{2+}$ acidified with dilute sulphuric acid.
- Stage 3 – The contents of the flask are heated gently.
- Stage 4 – The cooled contents of the flask are titrated with aqueous potassium manganate(VII) in acidic conditions to find the amount of unreacted $Fe^{2+}$.

(i) The reduction half-equation for manganese(IV) oxide in the presence of dilute acid is shown below.

$$MnO_2(s) + 4H^+(aq) + 2e^- \rightarrow Mn^{2+}(aq) + 2H_2O(l)$$

Construct the balanced equation for the redox reaction between $Fe^{2+}(aq)$, $MnO_2(s)$ and $H^+(aq)$.

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[1]

(ii) In Stage 1 and Stage 2 a student uses a 0.504 g sample of impure $MnO_2$ and 100 $cm^3$ of 0.200 mol $dm^{-3}$ $Fe^{2+}$.

In Stage 4 the student determines that the amount of unreacted $Fe^{2+}$ is 0.0123 mol.

1 mol of $MnO_2$ reacts with 2 mol of $Fe^{2+}$.

Calculate the percentage purity of the impure sample of $MnO_2$.

percentage purity = ..... %

[3]

[Total 4 marks]

**6.** Ruthenium (Ru) is a metal in the second transition series. It forms complex ions with the following formulae.

**A** = $[Ru(H_2O)_6]^{3+}$

**B** = $[Ru(H_2O)_5Cl]^{2+}$

**C** = $[Ru(H_2O)_4Cl_2]^{+}$

(a) (i) What is the oxidation number of ruthenium in **B**?

oxidation number of ruthenium = .....

[1]

(ii) One of the complex ions, **A**, **B** or **C**, shows stereoisomerism.

Draw diagrams to show the structures of the two isomers.

[2]

(iii) Name this type of stereoisomerism.

.....

[1]

(b) The complex ion $[Ru(H_2O)_6]^{3+}$ can be converted into $[Ru(H_2O)_5Cl]^{2+}$.

(i) Suggest a suitable reagent for this conversion.

.....

[1]

(ii) What type of reaction is this?

.....

[1]

[Total 6 marks]

**7.** The standard electrode potential of $Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$ is +0.34 V.

A student measured the standard electrode potential of $Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$. She was surprised to see that the emf of the cell was less than the expected value of +0.34 V.

She decided to measure the concentration of the $Cu^{2+}(aq)$ ions in the solution by titration.

25.00 $cm^3$ of the solution containing $Cu^{2+}$ ions were pipetted into a volumetric flask and she made the volume up to 250.0 $cm^3$ with distilled water.

An excess of aqueous potassium iodide, KI, was added to 25.00 $cm^3$ of the diluted solution.
The iodine formed was titrated against 0.100 mol $dm^{-3}$ sodium thiosulphate, $Na_2S_2O_3$.

The volume of $Na_2S_2O_3(aq)$ used was 23.20 $cm^3$.

The equations for the formation and titration of iodine are given below.

$$2Cu^{2+}(aq) + 4I^-(aq) \rightarrow 2CuI(s) + I_2(aq)$$

$$I_2(aq) + 2S_2O_3^{2-}(aq) \rightarrow 2I^-(aq) + S_4O_6^{2-}(aq)$$

(i) State how the student would identify the end point of the titration.

.....

.....

[1]

(ii) Show that the concentration of the $Cu^{2+}(aq)$ ions was 0.93 mol $dm^{-3}$.

[4]

(iii) Explain, in terms of chemical equilibrium, why the emf of this cell was less than the standard electrode potential.

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[2]

[Total 7 marks]

**8.** Iron forms several complex ions in which the oxidation state of iron is +3.

(i) Complete the electronic configuration for an iron(III) ion, $Fe^{3+}$.

$1s^2 2s^2 2p^6$ .....

[1]

(ii) Explain, using electronic configuration, why iron is a transition element.

.....

.....

[1]

[Total 2 marks]

**9.** Iron forms several complex ions in which the oxidation state of iron is +3.

One of these complex ions is $[Fe(CN)_6]^{3-}$. This is called the hexacyanoferrate(III) ion. In the hexacyanoferrate(III) ion the cyanide ions, $CN^-$, act as ligands.

(i) Suggest why a cyanide ion can act as a ligand.

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.....

[1]

(ii) Draw the expected shape for the complex ion $[Fe(CN)_6]^{3-}$. Include bond angles and the name of the shape.

[2]

[Total 3 marks]

**10.** Iron forms several complex ions in which the oxidation state of iron is +3.

Excess aqueous sodium hydroxide is added to an aqueous solution containing $Fe^{3+}(aq)$.

(i) Describe what you would see happen.

.....

[1]

(ii) Write an ionic equation, including state symbols, for the reaction that takes place.

.....

[2]

[Total 3 marks]

**11.** An unusual compound of iron has been detected on the surface of the planet Mars. This compound contains the ferrate(VI) ion.

When chlorine is bubbled through a suspension of iron(III) oxide in concentrated aqueous sodium hydroxide, a solution of aqueous sodium ferrate(VI) forms.

The two relevant redox systems are shown below.

$$Cl_2(aq) + 2e^- \rightarrow 2Cl^-(aq)$$

$$Fe_2O_3(s) + 10OH^-(aq) \rightarrow 2FeO_4^{2-}(aq) + 5H_2O(l) + 6e^-$$

Construct the redox equation for the reaction between chlorine, iron(III) oxide and hydroxide ions.

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.....

.....

[Total 2 marks]

**12.** An unusual compound of iron has been detected on the surface of the planet Mars. This compound contains the ferrate(VI) ion.

A student uses 1.00 g of iron(III) oxide and makes, on crystallisation, 0.450 g of sodium ferrate(VI), $Na_2FeO_4$.

Calculate the percentage yield, by mass, of sodium ferrate(VI).

Show your working.

Express your answer to an appropriate number of significant figures.

percentage yield = ..... %

[Total 4 marks]

**13.** An unusual compound of iron has been detected on the surface of the planet Mars. This compound contains the ferrate(VI) ion.

Ferrate(VI) ions will decompose in acidic solution as shown in the equation below.

$$4FeO_4^{2-}(aq) + 2OH^+(aq) \rightarrow 4Fe^{3+}(aq) + 3O_2(g) + 10H_2O(l)$$

Explain, in terms of oxidation numbers, why this decomposition involves both reduction and oxidation.

.....

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.....

.....

[Total 2 marks]

**14.** An unusual compound of iron has been detected on the surface of the planet Mars. This compound contains the ferrate(VI) ion.

Aqueous sodium ferrate(VI) is a very powerful oxidising agent.

(i) Predict what you would see when aqueous sodium ferrate(VI) is added to aqueous potassium iodide.

Explain your answer.

.....

.....

[1]

(ii) Aqueous sodium ferrate(VI) will oxidise ammonia into substance **X**.

Suggest an identity for **X**.

.....

[1]

[Total 2 marks]

**15.** Under certain conditions, $VO^{2+}$ can be converted into $VO_2^{+}$ by reaction with $KMnO_4$. The equation for the reaction is shown below.

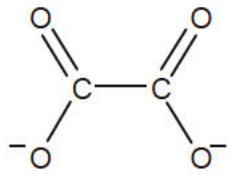
$$5VO^{2+} + H_2O + MnO_4^{-} \rightarrow 5VO_2^{+} + Mn^{2+} + 2H^{+}$$

What volume, in $cm^3$, of 0.0250 mol $dm^{-3}$ $KMnO_4$ would be required to convert 20.0 $cm^3$ of 0.100 mol $dm^{-3}$ $VO^{2+}$ into $VO_2^{+}$?

volume of $KMnO_4$ required = ..... $cm^3$

[Total 3 marks]

**16.** The ethanedioate ion, $C_2O_4^{2-}$, can act as a bidentate ligand when it forms complex ions with a transition metal ion. The structure of the ethanedioate ion is shown below.




(a) What do you understand by the term *bidentate ligand?*

.....

.....

[2]

(b) The ethanedioate ion readily forms an octahedral complex ion with $Cr^{3+}$.

Show the structure and charge of this complex ion.

[3]

[Total 5 marks]

**17.** The $Cr^{3+}$ ion forms a complex ion of formula $[Cr(C_2O_4)_2(H_2O)_2]^-$.

Use this complex to explain what is meant by the term stereoisomerism. Your answer should contain suitable diagrams.

[7]

Quality of Written Communication [1]

[Total 8 marks]

**18.** The compound $FeSO_4.7H_2O$ can be used to kill moss in grass. Iron(II) ions in a solution of $FeSO_4.7H_2O$ are slowly oxidised to form iron(III) ions.

Describe a test to show the presence of iron(III) ions in a solution of $FeSO_4.7H_2O$.

.....

.....

[Total 1 mark]

**19.** The compound $FeSO_47H_2O$ can be used to kill moss in grass.

The percentage purity of an impure sample of $FeSO_4.7H_2O$ can be determined by titration against potassium dichromate(VI), $K_2Cr_2O_7$, under acid conditions, using a suitable indicator.

During the titration, $Fe^{2+}(aq)$ ions are oxidised to $Fe^{3+}(aq)$ ions.

- Stage 1 – A sample of known mass of the impure $FeSO_4.7H_2O$ is added to a conical flask.
- Stage 2 – The sample is dissolved in an excess of dilute sulphuric acid.
- Stage 3 – The contents of the flask are titrated against $K_2Cr_2O_7(aq)$.

(i) The reduction half equation for acidified dichromate(VI) ions, $Cr_2O_7^{2-}$, is as follows.

$$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \longrightarrow 2Cr^{3+}(aq) + 7H_2O(l)$$

Construct the balanced equation for the redox reaction between $Fe^{2+}(aq)$, $Cr_2O_7^{2-}(aq)$ and $H^+(aq)$.

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[2]

(ii) In Stage 1, a student uses a 0.655 g sample of impure $FeSO_4.7H_2O$.

In Stage 3, the student uses 19.6 $cm^3$ of 0.0180 mol $dm^{-3}$ $Cr_2O_7^{2-}$ to reach the end-point.

One mole of $Cr_2O_7^{2-}$ reacts with 6 moles of $Fe^{2+}$.

Calculate the percentage purity of the impure sample of $FeSO_4.7H_2O$.

percentage purity .....

[4]

[Total 6 marks]

**20.** Dilute aqueous copper(II) sulphate contains $[Cu(H_2O)_6]^{2+}$ ions.

(a) Concentrated hydrochloric acid is added drop by drop to a small volume of dilute aqueous copper(II) sulphate. The equation for the reaction taking place is as follows.

$$[Cu(H_2O)_6]^{2+}(aq) + 4Cl^-(aq) \longrightarrow [CuCl_4]^{2-}(aq) + 6H_2O(l)$$

(i) Describe the observations that would be made during the addition of the concentrated hydrochloric acid.

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[1]

(ii) Describe the bonding within the complex ion, $[CuCl_4]^{2-}$.

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[2]

(b) Concentrated aqueous ammonia is added drop by drop to aqueous copper(II) sulphate until present in excess. Two reactions take place, one after the other, to produce the complex ion $[Cu(NH_3)_4(H_2O)_2]^{2+}(aq)$.

Describe the observations that would be made during the addition of concentrated aqueous ammonia.

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.....

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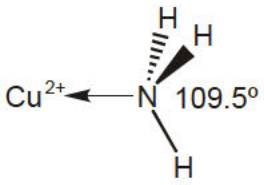
[2]

[Total 5 marks]

**21.** Ammonia is a simple molecule. The H—N—H bond angle in an isolated ammonia molecule is 107°.
The diagram shows part of the $[Cu(NH_3)_4(H_2O)_2]^{2+}$ ion and the H—N—H bond angle in the ammonia ligand.




Explain why the H—N—H bond angle in the ammonia ligand is 109.5° rather than 107°.

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[Total 3 marks]

**22.** Cobalt readily forms complex ions in which the cobalt has an oxidation state of +2.

One complex ion of cobalt is the hexaaquocobalt(II) ion $[Co(H_2O)_6]^{2+}$.

(i) What is the co-ordination number of $Co^{2+}$ in this complex ion?

.....

[1]

(ii) Water is acting as a ligand. Explain the meaning of the term *ligand*.

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[2]

[Total 3 marks]

**23.** Cobalt readily forms complex ions in which the cobalt has an oxidation state of +2.

$[Co(H_2O)_6]^{2+}$ readily undergoes the following reaction.

$$[Co(H_2O)_6]^{2+}(aq) + 4Cl^-(aq) \rightleftharpoons [CoCl_4]^{2-}(aq) + 6H_2O(l)$$

(i) What is the shape of each complex in this reaction?

$[Co(H_2O)_6]^{2+}$ shape .....

$[CoCl_4]^{2-}$ shape .....

[1]

(ii) What colour change would occur on going from left to right in this reaction?

from ..... to .....

[1]

(iii) What type of reaction is taking place when $[Co(H_2O)_6]^{2+}$ reacts with $Cl^-$?

.....

[1]

[Total 3 marks]

**24.** (a) $Co^{2+}$ forms the complex $[Co(NH_3)_4Cl_2]$. This complex exists as two stereoisomers.

(i) Draw diagrams to show the two isomeric forms of this complex.

[2]

(ii) What type of stereoisomerism is shown by this complex?

.....

[1]

(b) Cobalt also forms a complex with the formula $[Co(H_2NCH_2CH_2NH_2)_2Cl_2]$. This complex shows the same kind of isomerism as $[Co(NH_3)_4Cl_2]$ but it also shows a different type of stereoisomerism.

Draw diagrams to show the two isomers of this different type of stereoisomerism.

[2]

[Total 5 marks]

**25.** Chromium metal and its compounds have a number of important uses.

$Cr_2O_7^{2-}$ ions oxidise $I^-$ ions to $I_2$ under acid conditions according to the following equation.

$$Cr_2O_7^{2-}(aq) + 6I^-(aq) + 14H^+(aq) \rightleftharpoons 2Cr^{3+}(aq) + 3I_2(aq) + 7H_2O(l)$$

(i) If you carried out this reaction, how could you see that iodine is formed?

.....

.....

[1]

(ii) How could you use the formation of I2 in this reaction to determine the concentration of a solution of $Cr_2O_7^{2-}$ ions?

In your answer

- state the method you would use
- state the reagents used
- show how you would use your results.

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[4]

[Total 5 marks]

**26.** Copper and zinc are both d-block elements but only copper is a transition element. Copper forms compounds containing $Cu^{2+}$ or $Cu^{+}$ ions but zinc only forms compounds containing $Zn^{2+}$ ions.

(a) Use the electronic configurations of $Cu^{2+}$ and $Zn^{2+}$ to explain why copper is a transition element and zinc is not.

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[2]

(b) Suggest **two** differences between compounds containing $Zn^{2+}$ and $Cu^{2+}$ ions.

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[2]

[Total 4 marks]

**27.** Brass is an alloy of copper and zinc.

The percentage of copper and zinc in a sample of brass can be determined by reaction with hydrochloric acid. Only zinc reacts, as shown in the equation below.

$$Zn(s) + 2H^{+}(aq) \rightarrow Zn^{2+}(aq) + H_2(g)$$

- A sample of brass powder of known mass is added to an excess of 1.00 mol $dm^{-3}$ hydrochloric acid.
- The mixture is heated gently and the hydrogen collected is measured once the reaction has finished.

A student analyses a 1.23 g sample of brass using the method described.
The student collects 76.0 $cm^3$ of hydrogen at room temperature and pressure.
1 mol of gas molecules occupies 24.0 $dm^3$ at room temperature and pressure.

Calculate the percentage by mass of copper in the sample of brass.
Give your answer to an appropriate number of significant figures.

answer ..... %

[Total 3 marks]

**28.** Artists between the 13th and the 19th Centuries used a green pigment called verdigris.
The artists made the pigment by hanging copper foil over boiling vinegar.

During the preparation of verdigris, copper atoms are oxidised to copper(II) ions.

(i) Write the oxidation half equation for the conversion of copper atoms into copper(II) ions.

.....

[1]

(ii) The reduction half equation that takes place is as follows.

$$O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l)$$

Construct the equation for the redox reaction between copper, oxygen and hydrogen ions.

[1]

[Total 2 marks]

**29.** Artists between the 13th and the 19th Centuries used a green pigment called verdigris. The artists made the pigment by hanging copper foil over boiling vinegar.

A sample of verdigris has the formula $[(CH_3COO)_2Cu]_2.Cu(OH)_2.\mathbf{x}H_2O$.
Analysis of the sample shows that it contains 16.3% water by mass.
Calculate the value of **x** in the formula.

answer .....

[Total 3 marks]

**30.** In this question, one mark is available for the quality of spelling, punctuation and grammar.

Iron and its compounds take part in several different types of reaction including ligand substitution, precipitation and redox.

For each type of reaction

- give an example, taken from the chemistry of iron or its compounds
- state what you would see
- write a balanced equation for your example.

[9]

Quality of Written Communication [1]

[Total 10 marks]

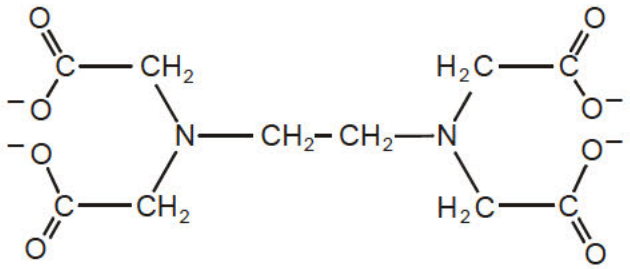
**31.** The $edta^{4-}$ ion forms complex ions with $Ni^{2+}(aq)$.

(a) Complete the electronic configuration of the $Ni^{2+}$ ion.

$1s^2 2s^2 2p^6$ .....

[1]

(b) The $edta^{4-}$ ion has the following structure.



(i) Put a ring around two different types of atom in the $edta^{4-}$ ion that are capable of forming a dative covalent bond with the $Ni^{2+}$ ion.

[2]

(ii) What feature of these atoms allows them to form a bond with $Ni^{2+}$?

.....

[1]

[Total 4 marks]

**32.** Platinum forms complexes with a co-ordination number of 4.

(a) (i) Explain the term *co-ordination number*.

.....

.....

[1]

(ii) State the shape of these platinum complexes.

.....

[1]

(b) The tetrachloroplatinate(II) ion readily undergoes the following reaction.

$$[PtCl_4]^x + 2NH_3 \rightleftharpoons [Pt(NH_3)_2Cl_2]^y + 2Cl^-$$

(i) What type of reaction is this?

.....

[1]

(ii) Suggest values for x and y in the equation.

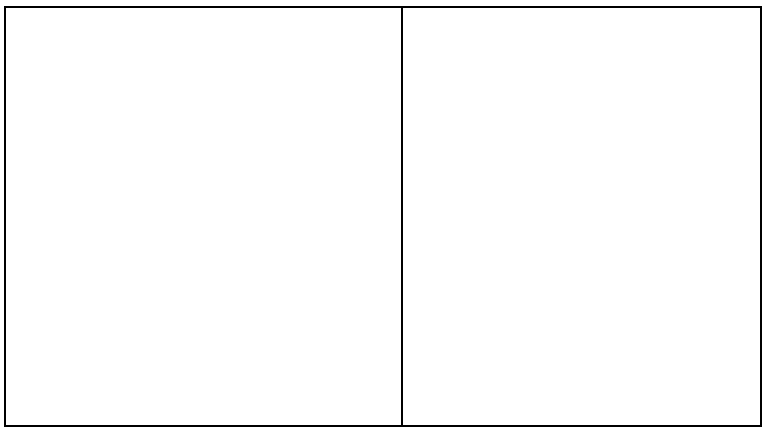
x = ……

y = ……

[2]

(c) The complex $[Pt(NH_3)_2Cl_2]^y$ exists in two isomeric forms.

(i) Draw diagrams to show the structure of these isomers.



[2]

(ii) What type of isomerism is this?

.....

[1]

(iii) One of the isomers of $[Pt(NH_3)2Cl_2]^y$ is an important drug used in the treatment of cancer.

How does this drug help in the treatment of cancer?

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[2]

[Total 10 marks]

**33.** Vanadium can exist in a number of different oxidation states. One compound of vanadium is ammonium vanadate(V) and this contains the ion $VO_3^-$. This can be reduced to $V^{2+}$ in several steps, using zinc metal and aqueous sulphuric acid.

(a) 25.0 $cm^3$ of 0.100 mol $dm^{-3}$ ammonium vanadate(V) is completely reduced to $V^{2+}(aq)$ using zinc and aqueous sulphuric acid. The resulting solution is titrated with 0.0500 mol $dm^{-3}$ $MnO_4^-(aq)$ and 30.0 $cm^3$ is required to oxidise the $V^{2+}(aq)$ back to $VO_3^-(aq)$.

The half equation for acidified $MnO_4^-$ acting as an oxidising agent is shown below.

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

Show that the vanadium has changed oxidation state from +2 to +5 in this titration.

[4]

(b) Suggest an equation for the oxidation of $V^{2+}(aq)$ to $VO_3^-(aq)$ by $MnO_4^-(aq)$ under acid conditions.

.....

[2]

[Total 6 marks]

**34.** A moss killer contains iron(II) sulphate.

Some of the iron(II) sulphate gets oxidised to form iron(III) sulphate. During the oxidation iron(II) ions, $Fe^{2+}$, react with oxygen, $O_2$, and hydrogen ions to make water and iron(III) ions, $Fe^{3+}$.

(a) Complete the electronic configuration for Fe3+ and use it to explain why iron is a transition element.

$Fe^{3+}$:$1s^2 2s^2 2p^6$ .....

.....

.....

[2]

(b) State **two** typical properties of **compounds** of a transition element.

1 .....

2 .....

[2]

(c) Describe how aqueous sodium hydroxide can be used to distinguish between aqueous iron(II) sulphate and aqueous iron(III) sulphate.

.....

.....

.....

[2]

(d) Construct the equation for the oxidation of acidified iron(II) ions by oxygen.

.....

[2]

[Total 8 marks]

**35.** The percentage by mass of iron in a sample of moss killer can be determined by titration against acidified potassium manganate(VII).

- Stage 1 – A sample of moss killer is dissolved in excess sulphuric acid.
- Stage 2 – Copper turnings are added to the acidified sample of moss killer and the mixture is boiled carefully for five minutes. Copper reduces any iron(III) ions in the sample to give iron(II) ions.
- Stage 3 – The reaction mixture is filtered into a conical flask to remove excess copper.
- Stage 4 – The contents of the flask are titrated against aqueous potassium manganate(VII).

(i) Suggest why it is important to remove all the copper in stage 3 before titrating in stage 4.

.....

.....

[1]

(ii) The ionic equation for the redox reaction between acidified $MnO_4^-$ and $Fe^{2+}$ is given below.

$$MnO_4^-(aq) + 8H^+(aq) + 5Fe^{2+}(aq) \rightarrow Mn^{2+}(aq) + 4H_2O(l) + 5Fe^{3+}(aq)$$

Explain, in terms of electron transfer, why this reaction involves both oxidation and reduction.

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.....

.....

[2]

(iii) A student analyses a 0.675 g sample of moss killer using the method described.

In stage 4, the student uses 22.5 $cm^3$ of 0.0200 mol $dm^{-3}$ $MnO_4^-$ to reach the endpoint.

Calculate the percentage by mass of iron in the moss killer.

percentage .....

[4]

[Total 7 marks]

**36.** Aqueous copper(II) sulphate contains $[Cu(H_2O)_6]^{2+}$ ions. Aqueous ammonia is added drop by drop to a small volume of aqueous copper(II) sulphate. Two reactions take place, one after the other, as shown in the equations.

$$[Cu(H_2O)_6]^{2+}(aq) + 2OH^-(aq) \rightarrow Cu(OH)_2(s) + 6H_2O(l)$$

$$Cu(OH)_2(s) + 2H_2O(l) + 4NH_3(aq) \rightarrow [Cu(NH_3)_4(H_2O)_2]^{2+}(aq) + 2OH^-(aq)$$

(a) Describe the observations that would be made as ammonia is added drop by drop until it is in an excess.

.....

.....

[2]

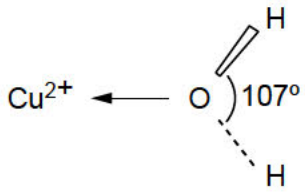
(b) Draw the shape for the $[Cu(H_2O)_6]^{2+}$ ion. Include the bond angles in your diagram.

[2]

[Total 4 marks]

**37.** Water is a simple molecule. The H—O—H bond angle in an isolated water molecule is 104.5°.

The diagram shows part of the $[Cu(H_2O)_6]^{2+}$ ion and the H—O—H bond angle in the water ligand.




Explain why the H—O—H bond angle in the water ligand is 107° rather than 104.5°.

.....

.....

.....

.....

[Total 3 marks]

**38.** Transition metals readily form complex ions when they are combined with a suitable ligand.

What is meant by the following terms?

(i) *complex ion*

.....

.....

[1]

(ii) *ligand*

.....

.....

[2]

[Total 3 marks]

**39.** (a) A common ligand which combines with a number of transition metal ions is ethane-1,2-diamine, $H_2NCH_2CH_2NH_2$. This is a bidentate ligand.

Explain the meaning of the term *bidentate*.

.....

.....

[1]

(b) The complex $[CoCl_2(H_2NCH_2CH_2NH_2)_2]$ is a neutral molecule. It shows two types of stereoisomerism. Use this molecule to explain what you understand by the term *stereoisomerism*. Your answer should include diagrams to show clearly the structures of the different isomers in both types of stereoisomerism.

.....

.....

.....

.....

.....

.....

.....

.....

.....

[7]

[Total 8 marks]

**40.** Potassium dichromate(VI) can be used in a number of redox reactions. The standard electrode potentials for two half reactions are given below.

$$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O \qquad E^\ominus = +1.33\ V$$

$$I_2 + 2e^- \rightleftharpoons 2I^- \qquad E^\ominus = +0.54\ V$$

Acidified potassium dichromate(VI) is added to aqueous potassium iodide to give aqueous iodine.

(i) Construct an ionic equation to show the reaction taking place when acidified potassium dichromate(VI) is added to aqueous potassium iodide.

.....

.....

.....

[2]

(ii) An excess of aqueous sodium thiosulphate was then added. Describe and explain what you would see.

.....

.....

.....

.....

[3]

[Total 5 marks]

**41.** In this question, one mark is available for the quality of use and organisation of scientific terms.

Copper and iron are typical transition elements. One of the characteristic properties of a transition element is that it can form complex ions.

- Explain in terms of electronic configuration why copper is a transition element.
- Give an example of a complex ion that contains copper. Draw the three dimensional shape of the ion and describe the bonding within this complex ion.
- Transition elements show typical metallic properties. Describe **three other** typical properties of transition elements. Illustrate each property using copper or iron or their compounds.

[11]

Quality of Written Communication [1]

[Total 12 marks]

**42.** Brass is a widely used alloy of copper. It is possible to analyse a sample of brass by initially dissolving it in concentrated nitric acid.

(a) (i) What other metal is present in brass?

.....

[1]

(ii) Give **one** common use for brass and state the property of brass which makes it ideal for that purpose.

.....

.....

[1]

(b) During the analysis of brass, 1.65 g of the alloy was reacted with concentrated nitric acid. The resulting solution was neutralised, transferred to a volumetric flask and made up to 250 $cm^3$ using distilled water.

An excess of aqueous potassium iodide was added to a 25.0 $cm^3$ portion of the solution from the volumetric flask and the liberated iodine was titrated with 0.100 mol $dm^{-3}$ sodium thiosulphate. 20.0 $cm^3$ of aqueous sodium thiosulphate were required to remove the iodine.

(i) What could be used to neutralise the excess nitric acid?

.....

[1]

(ii) What indicator is used in the titration of iodine with sodium thiosulphate?

.....

[1]

(iii) When is this indicator added to the titration mixture?

.....

[1]

(c) The reactions taking place in this titration may be summarised as follows.

$$2Cu^{2+} + 4I^- \rightarrow 2CuI + I_2$$

$$I_2 + 2S_2O_3^{2-} \rightarrow 2I^- + S_4O_6^{2-}$$

(i) Calculate the amount, in moles, of sodium thiosulphate in 20.0 $cm^3$ of solution.

answer ..... mol

[1]

(ii) For every one mole of $Cu^{2+}$ ions present in solution, deduce the amount, in moles, of $S_2O_3^{2-}$ ions needed for the titration.

answer ..... mol

[1]

(iii) What is the amount, in moles, of $Cu^{2+}$ ions present in 25.00 $cm^3$ of solution?

answer ..... mol

[1]

(iv) Calculate the percentage by mass of copper in the sample of brass.

answer ..... % Cu

[3]

[Total 11 marks]

**43.** The $Co^{2+}$ ion can form complexes with two different co-ordination numbers.

(a) What is meant by the *co-ordination number* of a complex ion?

.....

.....

[1]

(b) The following equilibrium is readily established.

$$[Co(H_2O)_6]^{2+} + 4Cl^- \rightleftharpoons [CoCl_4]^{2-} + 6H_2O$$

(i) In the boxes below, draw the shape of each complex ion.

| | | |
|---|---|---|
| $[Co(H_2O)_6]^{2+}$ | | $[CoCl_4]^{2-}$ |

[2]

(ii) What colour change would you expect to see when an excess of $Cl^-$ is added to $[Co(H_2O)_6]^{2+}$?

from ..... to .....

[2]

(iii) Describe how you would move the position of this equilibrium to the left.

.....

[1]

[Total 6 marks]

**44.** In this question, one mark is available for the quality of use and organisation of scientific terms.

Stereoisomerism is very common in transition metal complexes. Some complexes have found an important use in the treatment of cancer.

(i) Name a transition metal complex used in the treatment of cancer.

.....

[1]

(ii) Describe how this complex helps in the treatment of cancer.

.....

.....

.....

[2]

[Total 3 marks]

**45.** Describe the types of stereoisomerism found in transition metal complexes.

Use suitable examples to illustrate your answer.

[8]

Quality of Written Communication [1]

[Total 9 marks]