

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.



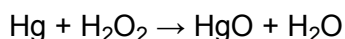
In your answer you should make clear how your diagrams illustrate the type of stereoisomerism involved.

[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.



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+}	$[\text{Xe}]4f^{14}5d^{10}6s^1$
Hg^{2+}	$[\text{Xe}]4f^{14}5d^{10}$

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

.....

[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 $\text{Fe}^{2+}(\text{aq})$.

State what you would observe.

.....

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

.....

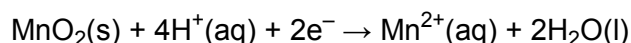
[2]

[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.



Construct the balanced equation for the redox reaction between $\text{Fe}^{2+}(\text{aq})$, $\text{MnO}_2(\text{s})$ and $\text{H}^+(\text{aq})$.

.....

.....

.....

[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 $0.200 \text{ mol dm}^{-3} \text{ Fe}^{2+}$.

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+} .

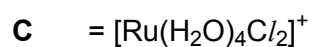
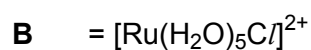
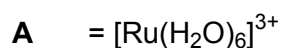
Calculate the percentage purity of the impure sample of MnO_2 .

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) (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 $[\text{Ru}(\text{H}_2\text{O})_6]^{3+}$ can be converted into $[\text{Ru}(\text{H}_2\text{O})_5\text{Cl}]^{2+}$.

(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 $\text{Cu}^{2+}(\text{aq}) + 2\text{e}^{-} \rightleftharpoons \text{Cu}(\text{s})$ is +0.34 V.

A student measured the standard electrode potential of $\text{Cu}^{2+}(\text{aq}) + 2\text{e}^{-} \rightleftharpoons \text{Cu}(\text{s})$. 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 $\text{Cu}^{2+}(\text{aq})$ ions in the solution by titration.

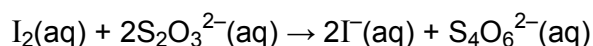
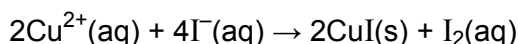
25.00 cm³ of the solution containing Cu^{2+} ions were pipetted into a volumetric flask and she made the volume up to 250.0 cm³ with distilled water.

An excess of aqueous potassium iodide, KI, was added to 25.00 cm³ of the diluted solution.

The iodine formed was titrated against 0.100 mol dm⁻³ sodium thiosulphate, Na₂S₂O₃.

The volume of Na₂S₂O₃(aq) used was 23.20 cm³.

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



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

.....
.....

[1]

(ii) Show that the concentration of the $\text{Cu}^{2+}(\text{aq})$ 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 $[\text{Fe}(\text{CN})_6]^{3-}$. 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.

.....
.....

[1]

- (ii) Draw the expected shape for the complex ion $[\text{Fe}(\text{CN})_6]^{3-}$. 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 $\text{Fe}^{3+}(\text{aq})$.

- (i) Describe what you would see happen.

.....

[1]

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

.....

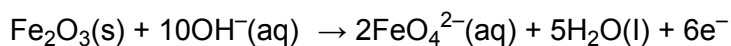
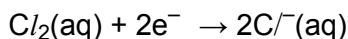
[2]

[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.



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

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

[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.

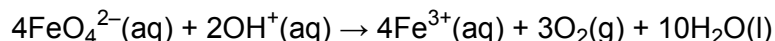
Express your answer to an appropriate number of significant figures.

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.



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**.

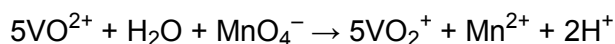
Suggest an identity for **X**.

.....

[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.

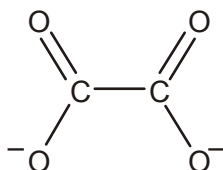


What volume, in cm^3 , of $0.0250 \text{ mol dm}^{-3}$ KMnO_4 would be required to convert 20.0 cm^3 of $0.100 \text{ mol dm}^{-3}$ VO^{2+} into VO_2^+ ?

volume of KMnO_4 required = cm^3

[Total 3 marks]

16. The ethanedioate ion, $\text{C}_2\text{O}_4^{2-}$, 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 $[\text{Cr}(\text{C}_2\text{O}_4)_2(\text{H}_2\text{O})_2]^-$.

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 $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ can be used to kill moss in grass. Iron(II) ions in a solution of $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ are slowly oxidised to form iron(III) ions.

Describe a test to show the presence of iron(III) ions in a solution of $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$.

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.....

[Total 1 mark]

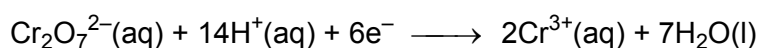
19. The compound $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ can be used to kill moss in grass.

The percentage purity of an impure sample of $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ can be determined by titration against potassium dichromate(VI), $\text{K}_2\text{Cr}_2\text{O}_7$, under acid conditions, using a suitable indicator.

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

- Stage 1 – A sample of known mass of the impure $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ 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 $\text{K}_2\text{Cr}_2\text{O}_7(\text{aq})$.

- (i) The reduction half equation for acidified dichromate(VI) ions, $\text{Cr}_2\text{O}_7^{2-}$, is as follows.



Construct the balanced equation for the redox reaction between $\text{Fe}^{2+}(\text{aq})$, $\text{Cr}_2\text{O}_7^{2-}(\text{aq})$ and $\text{H}^+(\text{aq})$.

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.....
.....

[2]

(ii) In Stage 1, a student uses a 0.655 g sample of impure $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$.

In Stage 3, the student uses 19.6 cm^3 of $0.0180 \text{ mol dm}^{-3} \text{ Cr}_2\text{O}_7^{2-}$ to reach the end-point.

One mole of $\text{Cr}_2\text{O}_7^{2-}$ reacts with 6 moles of Fe^{2+} .

Calculate the percentage purity of the impure sample of $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$.

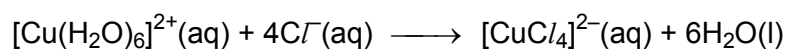
percentage purity

[4]

[Total 6 marks]

20. Dilute aqueous copper(II) sulphate contains $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ 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.



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

.....

[1]

(ii) Describe the bonding within the complex ion, $[\text{CuCl}_4]^{2-}$.

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

[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 $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}(\text{aq})$.

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

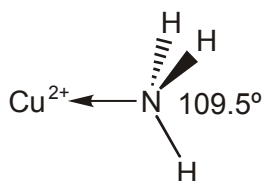
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[2]

[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 $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ 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 hexaaquacobalt(II) ion $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$.

(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*.

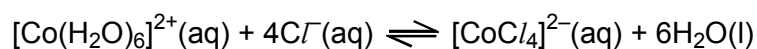
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[2]

[Total 3 marks]

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

$[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ readily undergoes the following reaction.



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

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

$[\text{CoCl}_4]^{2-}$ 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 $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ reacts with Cl^- ?

.....

[1]

[Total 3 marks]

24. (a) Co^{2+} forms the complex $[\text{Co}(\text{NH}_3)_4\text{Cl}_2]$. 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 $[\text{Co}(\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2)_2\text{Cl}_2]$. This complex shows the same kind of isomerism as $[\text{Co}(\text{NH}_3)_4\text{Cl}_2]$ but it also shows a different type of stereoisomerism.

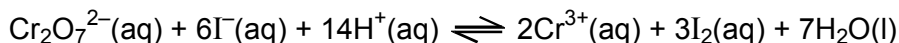
Draw diagrams to show the two isomers of this different type of stereoisomerism.

[2]

[Total 5 marks]

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

$\text{Cr}_2\text{O}_7^{2-}$ ions oxidise I^- ions to I_2 under acid conditions according to the following equation.



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

.....
.....

[1]

(ii) How could you use the formation of I_2 in this reaction to determine the concentration of a solution of $\text{Cr}_2\text{O}_7^{2-}$ 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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.....
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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.

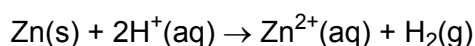
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[2]

[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.



- 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.

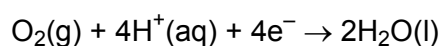
During the preparation of verdigris, copper atoms are oxidised to copper(II) ions.

- (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.



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 $[(\text{CH}_3\text{COO})_2\text{Cu}]_2 \cdot \text{Cu}(\text{OH})_2 \cdot x\text{H}_2\text{O}$. 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]

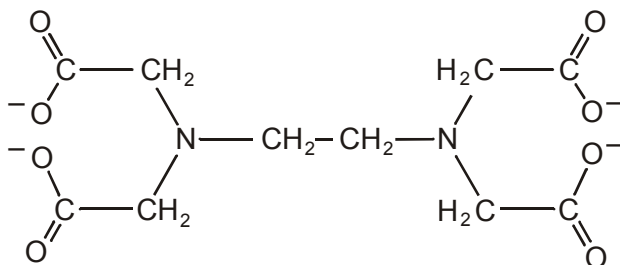
31. The edta^{4-} ion forms complex ions with $\text{Ni}^{2+}(\text{aq})$.

- (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 Ni²⁺?

.....

[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.



(i) What type of reaction is this?

.....

[1]

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

x =

y =

[2]

(c) The complex $[\text{Pt}(\text{NH}_3)_2\text{Cl}_2]^y$ exists in two isomeric forms.

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

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[2]

(ii) What type of isomerism is this?

.....

[1]

(iii) One of the isomers of $[\text{Pt}(\text{NH}_3)_2\text{Cl}_2]^y$ is an important drug used in the treatment of cancer.

How does this drug help in the treatment of cancer?

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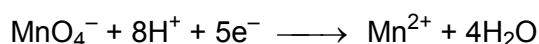
[2]

[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 $0.100 \text{ mol dm}^{-3}$ ammonium vanadate(V) is completely reduced to $\text{V}^{2+}(\text{aq})$ using zinc and aqueous sulphuric acid. The resulting solution is titrated with $0.0500 \text{ mol dm}^{-3} \text{ MnO}_4^-(\text{aq})$ and 30.0 cm^3 is required to oxidise the $\text{V}^{2+}(\text{aq})$ back to $\text{VO}_3^-(\text{aq})$.

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



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

[4]

- (b) Suggest an equation for the oxidation of $\text{V}^{2+}(\text{aq})$ to $\text{VO}_3^-(\text{aq})$ by $\text{MnO}_4^-(\text{aq})$ 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 Fe^{3+} 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]

