

1. (a) Write the electronic structure of a manganese atom and a  $\text{Mn}^{2+}$  ion.

		3d					4s
Mn	[Ar]						<div style="border: 1px solid black; width: 100%; height: 20px;"></div> <div style="border: 1px solid black; width: 100%; height: 20px;"></div>
$\text{Mn}^{2+}$	[Ar]						<div style="border: 1px solid black; width: 100%; height: 20px;"></div> <div style="border: 1px solid black; width: 100%; height: 20px;"></div>

(2)

(b) Solutions of manganese(II) sulphate contain the hydrated manganese(II) ion.

(i) Write the formula of this ion.

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(1)

(ii) When aqueous ammonia is added to a solution of manganese(II) sulphate, a buff coloured precipitate is obtained. Write an **ionic equation** for this reaction and state the type of reaction taking place.

Equation .....

Type of reaction .....

(3)

(iii) The precipitate produced slowly darkens on exposure to air. Suggest a reason for this and state **two** characteristic properties of transition elements that are being shown by manganese.

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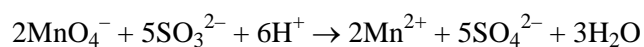
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(4)

- (c) Potassium manganate(VII),  $\text{KMnO}_4$ , reacts with sulphite ions,  $\text{SO}_3^{2-}$ , in acidic solution according to the equation



Sodium sulphite,  $\text{Na}_2\text{SO}_3$ , is slowly oxidised in air to sodium sulphate,  $\text{Na}_2\text{SO}_4$ , and hence it is very difficult to keep it pure.

1.75 g of an impure sample of sodium sulphite was dissolved in water and made up to  $250 \text{ cm}^3$  with distilled water.  $25.0 \text{ cm}^3$  of this solution required  $22.8 \text{ cm}^3$  of  $0.0216 \text{ mol dm}^{-3}$  potassium manganate(VII) solution for complete oxidation.

- (i) Calculate the change in oxidation number of sulphur in the reaction of sulphite ions with manganate(VII) ions.

(1)

- (ii) Calculate the amount (in moles) of manganate(VII) ions used in the titration.

(1)

- (iii) Calculate the amount (in moles) of sodium sulphite present in  $25.0 \text{ cm}^3$  of the solution.

(1)

(iv) Calculate the total mass of pure sodium sulphite in 250 cm<sup>3</sup> of the solution.

(2)

(v) Calculate the percentage purity of the sample of sodium sulphite.

(1)

(Total 16 marks)

2. This question is about Group 7 of the Periodic Table - the halogens. The standard electrode potentials for these elements are given below.

Electrode reaction	$E^{\ominus} / \text{V}$
$\frac{1}{2} \text{F}_2 + \text{e}^- \rightleftharpoons \text{F}^-$	+2.87
$\frac{1}{2} \text{Cl}_2 + \text{e}^- \rightleftharpoons \text{Cl}^-$	+1.36
$\frac{1}{2} \text{Br}_2 + \text{e}^- \rightleftharpoons \text{Br}^-$	+1.07
$\frac{1}{2} \text{I}_2 + \text{e}^- \rightleftharpoons \text{I}^-$	+0.54

(a) (i) Define the term *standard electrode potential*.

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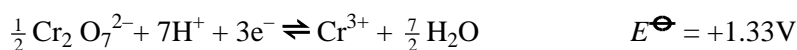
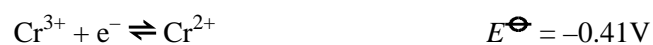
(2)

(ii) State which element or ion in the table above is the strongest oxidising agent.

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(1)

(b) The standard electrode potentials for chromium(III) changing to chromium(II) and for chromium(VI) changing to chromium(III) are given below.



(i) On the basis of the data provided, list those halogens which will oxidise chromium(II) to chromium(III).

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(1)

(ii) On the basis of the data provided, list those halogens which will oxidise chromium(II) to chromium(III) but not to chromium(VI).

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(1)

- (iii) Chromium(II) in aqueous solution is sky blue while aqueous chromium(III) solution is dark green. Describe how you would show that your prediction in part (ii) actually worked in practice.

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(2)

3. (a) Complete the electronic structure of a scandium atom, a chromium atom and a  $\text{Cr}^{3+}$  ion.

	$3d$		$4s$
Sc [Ar]	<div style="width: 30%;"></div> <div style="width: 30%;"></div> <div style="width: 30%;"></div>		
Cr [Ar]	<div style="width: 30%;"></div> <div style="width: 30%;"></div> <div style="width: 30%;"></div>		
$\text{Cr}^{3+}$ [Ar]	<div style="width: 30%;"></div> <div style="width: 30%;"></div> <div style="width: 30%;"></div>		

(3)

- (b) Both scandium and chromium are **d-block elements**, but only chromium is a **transition element**. Explain the meaning of these two terms.

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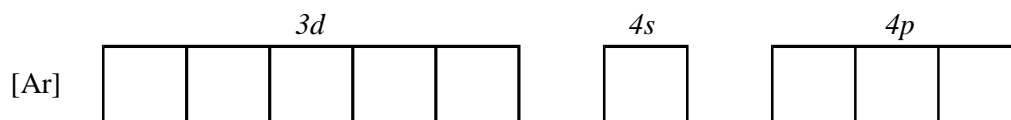
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(2)

(c)  $\text{Cr}^{3+}$  exists in aqueous solution as the green ion  $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$ .

(i) Complete the 'electrons in boxes' diagram for the complex ion  $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$ . Distinguish clearly the chromium electrons from those of the ligand.



(2)

(ii) Draw the  $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$  ion so as to clearly show its shape.

(1)

(iii) Explain the origin of the colour in  $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$ .

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(3)

(d) (i) State what you would see if aqueous sodium hydroxide was added drop by drop to a solution of  $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$  until the sodium hydroxide was in excess.

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(2)

(ii) What type of reaction is occurring in (i)?

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(1)

(Total 14 marks)

4. (a) The electronic configuration of a cobalt atom can be written as  $[\text{Ar}]3d^74s^2$ .  
Give the electronic configuration of the  $\text{Co}^{3+}$  ion.

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(1)

(b) (i) By reference to the standard electrode potentials given below, suggest a reducing agent which might reduce aqueous  $\text{Co}^{3+}$  ions to cobalt metal. Give your reasoning.

	$E^\ominus / \text{V}$
$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s})$	-0.76
$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Fe}(\text{s})$	-0.44
$\text{Co}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Co}(\text{s})$	-0.28
$\text{Sn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Sn}(\text{s})$	-0.14
$\text{O}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2\text{O}_2(\text{aq})$	+0.68
$\text{Co}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{Co}^{2+}(\text{aq})$	+1.82

Suitable reducing agent .....

Reasoning .....

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(3)

- (ii) Suggest **two** factors that might prevent a reducing agent from being as effective as the electrode potentials might seem to suggest.

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(2)

- (c) (i) Write the formula of the hexaaquacobalt(II) ion.

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(1)

- (ii) Give an equation, involving the hexaaquacobalt(II) ion, to illustrate the process of ligand exchange.

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(2)

(Total 9 marks)

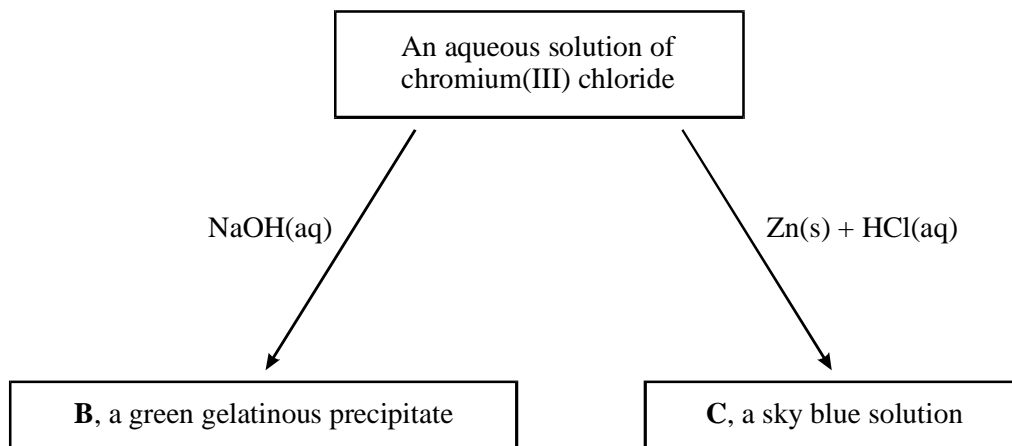
5. (a) State what is meant by the term **transition element**.

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(1)



(b) Two reactions of chromium(III) chloride are outlined below



(i) Give **two** features of chromium chemistry, illustrated in the above scheme, which are typical of a transition element.

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(2)

(ii) Identify the chromium-containing species in solution C.

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(1)

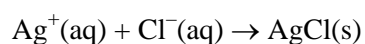
(c) Evaporating cold aqueous chromium(III) chloride produces violet crystals. However when hot aqueous chromium(III) chloride crystallises, green crystals result.

Both types of crystal have the same composition by mass: 19.5% chromium, 40.0% chlorine and 40.5% water.

(i) Show that the empirical formula of these two salts is  $\text{Cr}(\text{H}_2\text{O})_6\text{Cl}_3$ .

(2)

- (ii) The addition of excess aqueous silver nitrate to aqueous solutions of either of these two salts produces a precipitate of silver chloride, AgCl.



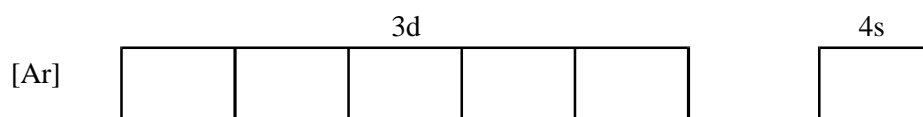
Under these conditions all the chloride from the violet salt is precipitated but only two-thirds of the chloride from the green salt.

Suggest formulae for the two salts given that water molecules may be either ligands in the complex ion or simple water of crystallisation and that chloride ions could be ligands in the complex ion or separate, simple ions.

(2)  
(Total 8 mark)

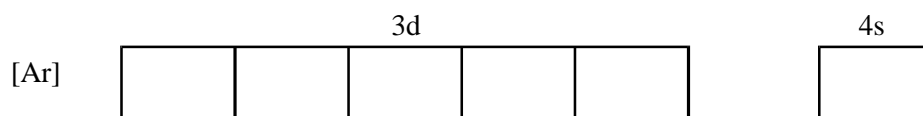
6. (a) Complete the following electronic configurations.

- (i) Cr:



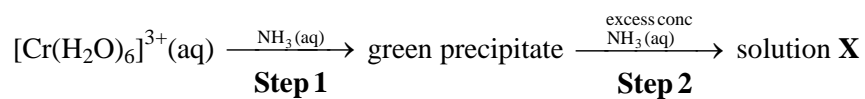
(1)

- (ii) Cr<sup>3+</sup>:



(1)

(b) Consider the following reaction scheme.



(i) Name the two types of bond present in the  $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$  ion.

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(2)

(ii) Name the type of reaction occurring in **Step 1**.

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(1)

(iii) Write a formula for the green precipitate.

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(1)

(iv) Name the type of reaction occurring in **Step 2**.

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(1)

(v) Give the formula of the chromium-containing species in solution **X**.

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(1)

(c) Explain the origin of the colour of transition metal aqua ions such as  $[\text{Cr}(\text{H}_2\text{O})_6]^{3+}$ .

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(3)  
(Total 11 marks)

7. (a) Complete the electronic configurations for:

(i) a nickel atom;

$1s^2$  .....

(1)

(ii) a  $\text{Ni}^{2+}$  ion.

$1s^2$  .....

(1)

- (b) Draw the ion hexaaqua nickel(II),  $[\text{Ni}(\text{H}_2\text{O})_6]^{2+}$ , so as to clearly show its shape. Label on your diagram each **type** of bond present.

(3)

- (c) If ammonia solution is added slowly to an aqueous solution containing nickel(II) ions, a pale green precipitate initially forms. This dissolves to give a blue solution in excess ammonia.

- (i) Give the formula of the pale green precipitate.

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(1)

- (ii) State the type of reaction occurring when ammonia solution is added as in (i) and explain the formation of the precipitate.

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(2)

(iii) Explain what occurs when excess ammonia is added.

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(2)

(Total 10 marks)

(i) Give **two** features of chromium chemistry, illustrated in the above scheme, which are typical of a transition element.

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(2)

(ii) Identify the chromium-containing species in solution C.

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(1)

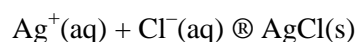
- (c) Evaporating cold aqueous chromium(III) chloride produces violet crystals. However when hot aqueous chromium(III) chloride crystallises, green crystals result.

Both types of crystal have the same composition by mass: 19.5% chromium, 40.0% chlorine and 40.5% water.

- (i) Show that the empirical formula of these two salts is  $\text{Cr}(\text{H}_2\text{O})_6\text{Cl}_3$ .

(2)

- (ii) The addition of excess aqueous silver nitrate to aqueous solutions of either of these two salts produces a precipitate of silver chloride,  $\text{AgCl}$ .



Under these conditions all the chloride from the violet salt is precipitated but only two-thirds of the chloride from the green salt.

Suggest formulae for the two salts given that water molecules may be either ligands in the complex ion or simple water of crystallisation and that chloride ions could be ligands in the complex ion or separate, simple ions.

(2)  
(Total 8 mark)

8. The concentration of iron(II) ions in a solution can be found by titration with standard potassium manganate(VII) solution. In the reaction iron(II) ions are oxidised to iron(III) ions.

If a solution contains both iron(II) and iron(III) ions, the concentration of each ion can be found by:

- titrating samples of the original solution with standard potassium manganate(VII) solution
- reacting samples of the original solution with zinc and dilute sulphuric acid and then titrating with the same potassium manganate(VII) solution.

The following standard electrode potentials are required:

	$E^\ominus/V$
$Zn^{2+} + 2e^- \rightleftharpoons Zn$	- 0.76
$Fe^{2+} + 2e^- \rightleftharpoons Fe$	- 0.44
$Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$	+ 0.77
$MnO_4^- + 8H^+ + 5e^- \rightleftharpoons Mn^{2+} + 4H_2O$	+ 1.51

- (a) (i) Use suitable  $E^\ominus$  values to show that both iron(II) and iron(III) ions in solution should react with zinc to give iron metal.

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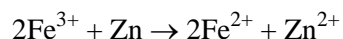
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(3)



- (ii) In practice the reaction produces only iron(II) ions and no iron metal.



Suggest a reason for this.

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(1)

- (b) (i) Derive the ionic equation for the reaction between iron(II) ions and manganate(VII),  $\text{MnO}_4^-$ , ions.

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(2)

- (ii) State what you would see as iron(II) ions in solution are titrated with potassium manganate(VII). How would you detect the endpoint of the titration?

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(3)

- (c) A solution containing both iron(II) and iron(III) ions was titrated with  $0.0200 \text{ mol dm}^{-3}$  potassium manganate(VII) solution,  $18.20 \text{ cm}^3$  being required.

Another portion of the same volume of the same solution was reacted with zinc, and then titrated with the same potassium manganate(VII) solution;  $25.30 \text{ cm}^3$  was required.  
What mass of zinc had reacted?

- (d) (i) Explain, including an equation, why aqueous solutions of hexaaqua ions such as  $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$  are acidic.

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(3)

- (ii) Suggest with reasons which of  $0.1 \text{ mol dm}^{-3}$  aqueous solutions of  $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$  and  $[\text{Fe}(\text{H}_2\text{O})_6]^{3+}$  would be the more acidic.

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(3)

(Total 20 marks)

9. (a) Complete the electronic configurations of

- (i) a zinc atom:

$1s^2$  .....

(1)

- (ii) a  $\text{Zn}^{2+}$  ion:

$1s^2$  .....

(1)

- (b) State why zinc is classified as a *d*-block element but not as a transition element.

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(2)

(c) Draw a 3-dimensional representation of the  $[\text{Zn}(\text{H}_2\text{O})_6]^{2+}$  ion, including the bond angles.

Indicate on your diagram the types of bonding present.

(4)

(d) (i) State what you would see when ammonia solution is added to an aqueous solution of zinc(II) ions, first in a small amount and then to excess.

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(2)

(ii) Give equations for the reactions that occur in (d)(i)

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(3)

(e) (i) Explain why  $[\text{Zn}(\text{H}_2\text{O})_6]^{2+}$  ions have no colour.

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(2)

(ii) Why is zinc chromate(VI),  $\text{ZnCrO}_4$ , bright yellow?

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(1)

(Total 16 marks)

10. (a) (i) Give the electronic configuration of:

Fe [Ar].....

$\text{Fe}^{2+}$  [Ar].....

(2)

- (ii) Draw the structure of the hexaaquairon(II) ion,  $[\text{Fe}(\text{H}_2\text{O})_6]^{2+}$ , so as to clearly show its shape.

(1)

- (iii) Give the equation for the complete reaction of sodium hydroxide solution with a solution of hexaaquairon(II) ions.

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(1)

- (iv) State what you would see if the product mixture in (iii) is left to stand in air.

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(1)

- (v) Give the equation for a reaction in which iron metal is used as a catalyst.

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(1)

(b) Consider the half reaction



(i) Define the term **standard electrode potential** with reference to this electrode.

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(3)

(ii) Explain, with the aid of an equation, why the value of  $E^{\ominus}$  suggests that iron will react with an aqueous solution of an acid to give  $\text{Fe}^{2+}$  ions and hydrogen gas.

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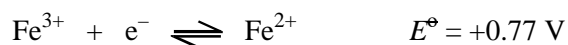
(3)

(iii) State why  $E^{\ominus}$  values cannot predict that a reaction will occur, only that it is possible.

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(1)

- (c) Use the following standard electrode potentials to explain why iron(III) iodide does **not** exist in aqueous solution.



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(2)

(Total 15 marks)

11. (a) The elements from scandium to zinc belong to the *d*-block. Some, but not all, of these elements are transition elements.

- (i) What is meant by the term **transition element**?

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(1)

- (ii) Which of the elements, from scandium to zinc inclusive, are in the *d*-block but are **not** transition elements?

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(1)

- (b) (i) Complete the electronic configurations of the  $\text{Fe}^{2+}$  and  $\text{Mn}^{2+}$  ions below.

$\text{Fe}^{2+}$  [Ar] .....

$\text{Mn}^{2+}$  [Ar] .....

(1)



(ii) Suggest why  $\text{Fe}^{2+}$  ions are readily oxidised to  $\text{Fe}^{3+}$  ions, but  $\text{Mn}^{2+}$  ions are **not** readily oxidised to  $\text{Mn}^{3+}$  ions.

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(2)

(c) Draw a diagram to show the three-dimensional structure of the  $[\text{Fe}(\text{CN})_6]^{4-}$  complex ion.

(2)

(d) A solution of potassium manganate(VII),  $\text{KMnO}_4$ , can be standardised by titration with arsenic(III) oxide,  $\text{As}_2\text{O}_3$ . In this reaction, 5 mol of arsenic(III) oxide are oxidised to arsenic(V) oxide,  $\text{As}_2\text{O}_5$ , by 4 mol of manganate(VII) ions,  $\text{MnO}_4^-$ .

Calculate the final oxidation number of the manganese.

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(4)

(e) Ammonium vanadate(V),  $\text{NH}_4\text{VO}_3$ , reacts with dilute sulphuric acid to form a solution containing yellow  $\text{VO}_2^+$  ions.

(i) Write an **ionic** equation for the reaction of the anion in  $\text{NH}_4\text{VO}_3$  with dilute sulphuric acid.

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(1)

(ii) Is the reaction in (i) a redox reaction? Justify your answer.

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(1)

(iii) Addition of zinc to the solution containing  $\text{VO}_2^+$  ions causes the colour to change from yellow to green then to blue, followed by green again and finally violet. State the formulae of the ions responsible for each of these colours.

The first green colour .....

The second green colour .....

The violet colour .....

(3)

(Total 16 marks)

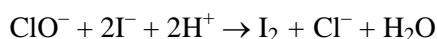
12. Domestic bleaches contain sodium chlorate(I), NaOCl.

- (a) Write the **ionic** equation to show the disproportionation of the chlorate(I) ion. Use oxidation numbers to explain the meaning of the term disproportionation in this reaction.

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(3)

- (b) Domestic bleaches are dilute solutions of sodium chlorate(I). The amount of ClO<sup>-</sup> ions in a sample can be found by reacting it with excess acidified potassium iodide solution.



The iodine produced is then titrated with standard sodium thiosulphate solution.

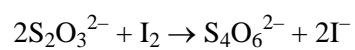
- 10.0 cm<sup>3</sup> of a domestic bleach was pipetted into a 250 cm<sup>3</sup> volumetric flask and made up to the mark with distilled water.
- A 25.0 cm<sup>3</sup> portion of the solution was added to excess acidified potassium iodide solution in a conical flask.
- This mixture was titrated with 0.100 mol dm<sup>-3</sup> sodium thiosulphate solution, using starch indicator added near the end point.
- The mean titre was 12.50 cm<sup>3</sup>.

- (i) Give the colour change you would see at the end point.

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(1)

- (ii) The equation for the reaction between iodine and thiosulphate ions is



Calculate the amount (moles) of chlorate(I) ions in  $1.00 \text{ dm}^3$  of the **original** bleach.

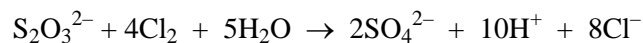
(5)

- (iii) Use the equation below to calculate the mass of chlorine available from  $1.00 \text{ dm}^3$  of the **original** bleach. Give your answer to 3 significant figures.



(1)

- (c) Sodium thiosulphate can be used to remove the excess chlorine from bleached fabrics.



By considering the change in oxidation number of sulphur, explain whether chlorine or iodine is the stronger oxidising agent when reacted with thiosulphate ions.

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(2)

- (d) Starch-iodide paper can be used to test for chlorine. It contains starch and potassium iodide.

Explain the reactions taking place when a piece of damp starch-iodide paper is put in a gas jar of chlorine. State what you would see.

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(2)

(Total 14 marks)



(iii) Explain why **Step 1** is a **deprotonation** reaction.

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(2)

(iv) Name the type of reaction occurring in **Step 2**.

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(1)

(v) Give an equation for the reaction in **Step 2**.

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(2)

(d) Explain why the hexaaquanickel(II) ion,  $[\text{Ni}(\text{H}_2\text{O})_6]^{2+}$ , is coloured.

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(3)

(Total 14 marks)