IB · DP · Chemistry

2 hours 13 questions

Structured Questions: Paper 2

13.1 Transition Metals

Easy (4 questions)	/29
Medium (5 questions)	/55
Hard (4 questions)	/31
Total Marks	**/115**

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Easy Questions

1 (a) Transition metals can form complex ions where ligands are coordinately bonded to the central metal ion.

i) Define the term *ligand.*

[1]

ii) State what is meant by the term *bidentate ligand*

[1]

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(2 marks)

(b) Transition metals are located in the d-block of the periodic table.

i) State the electron configuration of V^{2+}.

[1]

ii) Explain why scandium is not considered a transition metal.

[1]

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(2 marks)

(c) State the oxidation state of Fe in $[Fe(CN)_6]^{4-}$.

.....

(1 mark)

(d) Iron and zinc are in the d-block of the Periodic Table. Iron(II) ions, $[Fe(H_2O)_6]^{2+}$, form a pale green solution but zinc ions, $[Zn(H_2O)_6]^{2+}$, form a colourless solution.

i) Write the electron configuration of Zn^{2+}.

[1]

ii) Explain why zinc ions are colourless.

[2]

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(3 marks)

2 (a) A complex ion contains one Fe^{3+} ion, four ammonia molecules and two chloride ions.

State the formula of this complex ion.

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(1 mark)

(b) State **two** characteristic properties of transition elements.

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(2 marks)

(c) Transition metals can be used as successful catalysts in a range of reactions.

State what is meant by the term *homogeneous* catalyst.

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(1 mark)

(d) Transition metals can form complexes with different ligands.

Identify **one** species from the following list that does not act as a ligand and explain your answer.

CO H_2O SCN^- H_2

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(2 marks)

3 (a) Using section 16 of the data booklet, state the formula of a bidentate ligand.

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(1 mark)

State three factors that affect the value of the splitting energy, ΔE, in the d-orbitals.

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(b) **(3 marks)**

(c) Outline why transition metals form coloured compounds.

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(5 marks)

(d) Using section 15 of the data booklet, explain why adding ammonia to aqueous copper(II) ions results in a darker blue complex.

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(2 marks)

4 (a) Deduce the oxidation state of vanadium in the compound NH_4VO_3.

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(1 mark)

(b) Transition elements can be used to catalyse certain reactions.

Define the term *heterogeneous* in relation to catalysts.

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(1 mark)

(c) Outline the difference between diamagnetic and paramagnetic elements in terms of electron arrangement.

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(1 mark)

(d) Describe the splitting of the d orbitals in an octahedral crystal field.

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(1 mark)

Medium Questions

1 (a) a) Explain why transition metals exhibit variable oxidation states compared to the elements in group 1.

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(2 marks)

(b) b) Transition metal compounds and ions are often coloured. For example, $[Cr(H_2O)_6]^{3+}$ is green.

Explain why $[Cr(H_2O)_6]^{3+}$ and other complex ions are coloured.

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(3 marks)

(c) c) Water acts as a ligand when it reacts with zinc and cobalt ions, forming the complexes $[Zn(H_2O)_4]^{2+}$ and $[Co(H_2O)_6]^{2+}$

Explain how water acts as a ligand in forming these complexes and predict the shape of $[Co(H_2O)_6]^{2+}$.

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(3 marks)

(d) d) Explain why solutions containing $[Co(H_2O)_6]^{2+}$ are coloured but solutions containing $[Zn(H_2O)_4]^{2+}$ are not.

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(4 marks)

2 (a) a) Complete **Table 1** below to show the oxidation state of the **transition element.**

Table 1

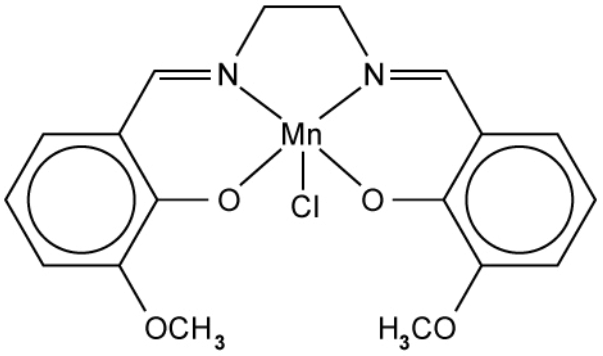
Ion	$[Cu(Cl_4)]^{2-}$	$[Fe(H_2O)_6]^{3+}$	$Cr_2O_7^{2-}$
Oxidation state			

(3 marks)

(b) b) Explain why chromium is the most paramagnetic element in the first transition series and why zinc is diamagnetic.

(3 marks)

c) EUK-134 is a complex ion of manganese(III) used in skin care products to protect against UV damage as it has antioxidant properties.



i) State the electron configuration of the manganese(III) ion in complex shown above

ii) State the name given to species that bond to a central metal ion, and identify the type of bond present.

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(c) **(3 marks)**

(d) d) Transition metals have certain characteristic properties.

State **two** properties that are involved in EUK-134 rapidly decreasing the concentration of oxidising agents.

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(2 marks)

3 (a) a) A characteristic property of transition elements, like chromium, is that they form coloured compounds. Using Section 17 of the Data Booklet, explain why $Ni^{2+}(aq)$ is green but $Sc^{3+}(aq)$ is colourless.

(5 marks)

(b) b) The colour intensity of solutions of complex ions is one method of determining the concentration of transition metal ions. Excess aqueous ammonia is sometimes added before measuring the absorption of copper(II) ions.

Describe why the addition of excess ammonia to aqueous copper(II) ions causes the shade of the blue colour to change.

(3 marks)

(c) c) Increasing the concentration of chloride ions in an aqueous solution of vanadium(III) chloride causes the vanadium complex to change from $[V(H_2O)_6]^{3+}$ to $[VCl(H_2O)_5]^{2+}$ to $[VCl_2(H_2O)_4]^{+}$

Outline what would happen to the wavelength at which the vanadium complex ions would absorb light as the concentration of chloride ions is increased, using Section 15 of the Data Booklet.

(2 marks)

d) Ferrocyanide salts, $[Fe(CN)_6]^{4-}$, are used in the production of Prussian blue, which was the first modern synthetic pigment.

i) Deduce the oxidation number of iron in $[Fe(CN)_6]^{4-}$

ii) Draw the abbreviated orbital diagram for the **iron ion in $[Fe(CN)_6]^{4-}$** using the arrow-in-box notation to represent electrons.

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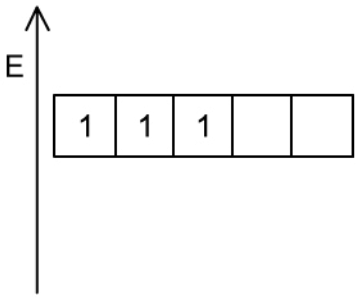
(d) **(2 marks)**

4 (a) a) The energy level diagram showing the electrons in the five 3d orbitals of a chromium atom is shown in the figure below.

Draw the completed diagram showing the d orbitals in $[Cr(H_2O)_6]^{3+}$ after splitting.



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(1 mark)

(b) a) State and explain what happens to the splitting of the d orbitals if the ligand is changed from H_2O to NH_3.

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(2 marks)

(c) c) Explain, in terms of acid-base theories, what type of a reaction is the formation of $[Fe(H_2O)_6]^{2+}$ from Fe^{2+} and water

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(2 marks)

(d) d) The complex ion $[Ni(NH_3)_6]^{2+}$ is blue and $[Ni(H_2O)_6]^{2+}$ is green

Explain why the $[Ni(H_2O)_6]^{2+}$ complex ion is coloured and outline why changing the identity of the ligand changes the colour of the ion.

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(4 marks)

5 (a) a) Dilute copper(II) chloride solution is light blue, while copper(I) chloride is colourless.

Describe how the blue colour is produced in the copper(II) chloride. Refer to Section 17 of the Data Booklet.

(4 marks)

(b) b) Explain why the copper(I) chloride is colourless.

(2 marks)

(c) c) When excess ammonia is added to copper(II) chloride solution, the dark blue complex ion, $[Cu(NH_3)_4(H_2O)_2]^{2+}$, forms.

State the molecular geometry of this complex ion, and the bond angles within it.

(2 marks)

(d) d) Outline the relationship between the Brønsted–Lowry and Lewis definitions of a base, referring to the ligands in the complex ion $[CuCl_4]^{2-}$.

(3 marks)

Hard Questions

1 (a) When chromium(III) sulfate dissolves in water, a green solution containing the $[Cr(H_2O)_6]^{3+}$ ion forms.

i) State the bond angles found in this complex ion.

[1]

ii) Explain why the chromium(III) complex ion is coloured.

[3]

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(4 marks)

(b) Vanadium(V) oxide is the catalyst used in the Contact process as shown by the reactions:

$$SO_2\,(g) + V_2O_5\,(s) \rightarrow SO_3\,(g) + V_2O_4\,(s)$$

$$V_2O_4\,(s) + ½O_2\,(g) \rightarrow V_2O_5\,(s)$$

i) Explain, using the equations, why V_2O_5 is a catalyst.

[1]

ii) Explain why V_2O_5 can act as a catalyst in this reaction.

[1]

.....

.....

(2 marks)

(c) Excess ammonia is added to a solution of Cu^{2+} ions resulting in the substitution of 4 ligands.

Using section 15 of the data booklet, explain why this reaction results in a shift in the wavelength of light absorbed by the Cu^{2+} complex.

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(1 mark)

2 (a) Iron is a transition element that forms several ions with iron in different oxidation states.

Deduce the condensed electron configuration of the iron cation that can form the complex ion $[Fe(CN)_6]^{4-}$.

.....

(1 mark)

(b) Co(III) has the same electron configuration as the iron cation in part(a).

Explain why, despite this, solutions of the two ions are different colours.

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(2 marks)

(c) Rhenium forms salts containing the perrhenate(VII) ion, ReO_4^-.

Suggest why the existence of salts containing an ion with this formula could be predicted. Refer to section 6 of the data booklet.

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(1 mark)

(d) Rhenium is used with platinum to speed up reactions used in the production of gasoline.

Predict **two** other chemical properties you would expect rhenium to have, given its position in the periodic table.

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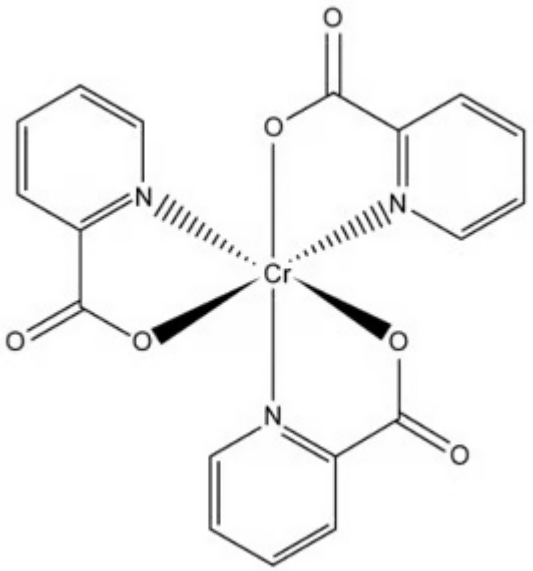
(2 marks)

3 (a) Chromium (III) picolinate, shown below, is often used in tablets as a nutritional supplement for chromium.



i) Draw the structure of the ligand in chromium(III) picolinate.

[1]

ii) State the coordination number of chromium in chromium(III) picolinate.

[1]

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(2 marks)

(b) A complex of cobalt has the following composition by mass:

Co, 21.98%; N, 31.35%; H, 6.81%; Cl, 39.86%

i) Calculate the empirical formula of this complex.

ii) The formula of this cobalt complex can be expressed in the form $[Co(L)_m]^{x+}(Cl^-)_n$. Suggest the chemical formula of $[Co(L)_m]^{x+}$.

[3]

(3 marks)

(c) $Ni(ClO_4)_2$ reacts with water to form the complex ion $[Ni(H_2O)_6][ClO_4]_2$.

Explain this reaction in terms of an acid-base theory.

(2 marks)

(d) Nickel(II) forms a complex ion with water, $[Ni(H_2O)_6]^{2+}$

i) Outline how the bond is formed between Ni^{2+} and H_2O during the formation of the complex.

[1]

ii} State the geometry of the complex formed.

[1]

(2 marks)

4 (a) 1,2-diaminoethane is a bidentate ligand which can form a complex with $[Co(NH_3)_4(H_2O)_2]^{2+}$. In this reaction, only the ammonia molecules are replaced.

i) Write an equation for this reaction.

[1]

ii) State the molecular geometry of the complex formed.

[1]

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(2 marks)

(b) Consider the complex $[Ni(NH_3)_6]Cl_2$

i) Deduce the condensed electron configuration of the Ni.

[1]

ii) Explain whether the complex is paramagnetic or diamagnetic.

[2]

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(3 marks)

(c) Explain why Ti forms variable oxidation states, but Ca only occurs in the +2 oxidation state.

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(2 marks)

(d) Explain the magnetic nature of the complex $[Cr(H_2O)_6]Cl_3$.

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(2 marks)