An Introduction to the Chemistry of the Transition Elements

Question Paper 5

Level	International A Level
Subject	Chemistry
Exam Board	CIE
Topic	An Introduction to the Chemistry of the Transition Elements
Sub-Topic	
Paper Type	Theory
Booklet	Question Paper 5

Time Allowed:	**80 minutes**
Score:	**/66**
Percentage:	**/100**

Grade Boundaries:

A*	A	B	C	D	E	U
>85%	777.5%	70%	62.5%	57.5%	45%	<45%

1 (a) (i) What is meant by the term *ligand* in the context of transition element chemistry?

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(ii) Decide which of the following species could be a ligand, and which could not be. Place a tick (✓) in the appropriate column.

species	can be a ligand	cannot be a ligand
OH^-		
NH_4^+		
CH_3OH		
CH_3NH_2		

[3]

(b) Read the following description of some reactions of copper(II) sulfate, and answer the questions that follow.

When 0.1 mol of white anhydrous $CuSO_4$ is dissolved in liquid ammonia at –33 °C, a deep blue solution **C** results.
When 0.2 mol of solid NaOH is added to solution **C**, and the ammonia solvent allowed to evaporate, a solid residue is obtained.
Heating this residue to 200 °C produces a dark coloured mixture of two solids.
When water is added to this mixture, a black solid **D** and a colourless solution **E** are formed. Neither **D** nor **E** contains nitrogen.
Adding $BaCl_2$(aq) to solution **E** produces a white precipitate **F**.
Solid **D** dissolves in HNO_3(aq) on warming, without evolution of gas, to give a pale blue solution containing $Cu(NO_3)_2$(aq).

(i) Suggest the formula of the compound contained in each of the following.

solution **C** .....

solid **D** .....

solution **E** .....

white precipitate **F** .....

(ii) Name the type of reaction that is occurring when **D** reacts with HNO_3(aq).

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[5]

(c) **(i)** Describe what you would observe when a solid sample of anhydrous $Cu(NO_3)_2$ is strongly heated.

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(ii) Write an equation for this reaction.

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[2]

[Total: 10]

2 **(a)** Explain why complexes of transition elements are often coloured.

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..... [3]

(b) When water is added to white anhydrous $CuSO_4$, the solid dissolves to give a blue solution. The solution changes to a yellow-green colour when concentrated $NH_4Cl(aq)$ is added to it. Concentrating the solution produces green crystals of an ammonium salt with the empirical formula $CuN_2H_8Cl_4$.
Explain these observations, showing your reasoning.

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..... [3]

(c) Copper can be recovered from low-grade ores by 'leaching' the ore with dilute H_2SO_4, which converts the copper compounds in the ore into $CuSO_4(aq)$. The concentration of copper in the leach solution can be estimated by adding an excess of aqueous potassium iodide, and titrating the iodine produced with standard $Na_2S_2O_3(aq)$.

$$2Cu^{2+} + 4I^- \rightarrow 2CuI + I_2$$
$$I_2 + 2S_2O_3^{2-} \rightarrow 2I^- + S_4O_6^{2-}$$

When an excess of KI(aq) was added to a 50.0 cm^3 sample of leach solution, and the resulting mixture titrated, 19.5 cm^3 of 0.0200 $mol\,dm^{-3}$ $Na_2S_2O_3(aq)$ were required to discharge the iodine colour.
Calculate the $[Cu^{2+}(aq)]$, and hence the percentage by mass of copper, in the leach solution.

percentage of copper = ...% [3]

[Total: 9]

3 **(a)** Explain what is meant by the term *transition element*.

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..... [1]

(b) Complete the electronic configuration of

(i) the vanadium atom, $1s^2 2s^2 2p^6$ .....

(ii) the Cu^{2+} ion. $1s^2 2s^2 2p^6$ .....

[2]

(c) List the **four** most likely oxidation states of vanadium.

..... [1]

(d) Describe what you would see, and explain what happens, when dilute aqueous ammonia is added to a solution containing Cu^{2+} ions, until the ammonia is in an excess.

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..... [5]

(e) Copper powder dissolves in an acidified solution of sodium vanadate(V), $NaVO_3$, to produce a blue solution containing VO^{2+} and Cu^{2+} ions.
By using suitable half-equations from the *Data Booklet*, construct a balanced equation for this reaction.

..... [2]

[Total: 11]

4 Metals play a vital part in biochemical systems. In this question you need to consider why some metals are essential to life, whilst others are toxic.

(a) For each of the metals, state where it might be found in a living organism, and what its chemical role is.

iron location in organism .....

role .....

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sodium location in organism .....

role .....

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zinc location in organism .....

role .....

.....

[6]

(b) Heavy metals such as mercury are toxic, and it is important that these do not enter the food chain.

(i) Give a possible source of mercury in the environment.

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(ii) Describe and explain **two** reasons why mercury is toxic, using diagrams and/or equations to help your explanation.

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[4]

[Total : 10]

5 One major difference between the properties of compounds of the transition elements and those of other compounds is that the compounds of the transition elements are often coloured.

(a) Explain in detail why many transition element compounds are coloured.

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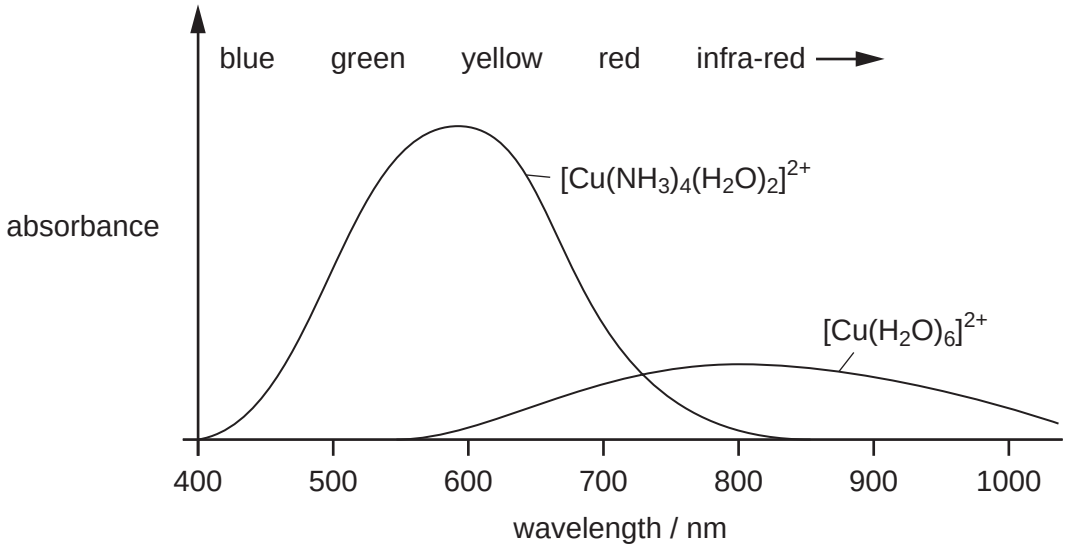
..... [3]

(b) The following graph shows the absorption spectrum of two complexes containing copper.



(i) State the colours of the following complex ions.

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

$[Cu(NH_3)_4(H_2O)_2]^{2+}$ .....

(ii) Using the spectra above give **two** reasons why the colour of the $[Cu(NH_3)_4(H_2O)_2]^{2+}$ ion is deeper (more intense) than that of the $[Cu(H_2O)_6]^{2+}$ ion.

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(iii) Predict the absorption spectrum of the complex $[Cu(NH_3)_2(H_2O)_4]^{2+}$, and sketch this spectrum on the above graph. [6]

(c) Copper forms a complex with chlorine according to the following equilibrium.

$$Cu^{2+}(aq) + 4Cl^{-}(aq) \rightleftharpoons [CuCl_4]^{2-}(aq)$$

(i) Write an expression for the equilibrium constant, K_c, for this reaction, stating its units.

K_c = ... units .....

(ii) The numerical value of K_c is 4.2×10^5.
Calculate the $[[CuCl_4]^{2-}]/[Cu^{2+}]$ ratio when $[Cl^-] = 0.20\,mol\,dm^{-3}$.

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[3]

[Total: 12]

6 Iron metal and its compounds are useful catalysts in certain reactions.

(a) **Apart from its catalytic activity**, state **two** properties of iron or its compounds that show that it is a transition element.

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.....[2]

(b) You are provided with a solution of $KMnO_4$ of known concentration in a burette.
Outline how you could use this solution to find out the concentration of $Fe^{2+}(aq)$ in a solution. You should include relevant equations for any reactions you describe.

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.....[4]

(c) For each of the following equations, write the oxidation number of the element printed **in bold** underneath its symbol, and balance the equation by adding appropriate numbers before each species.

(i) ..... $\mathbf{Mn}O_4^-$ + ... $\mathbf{S}O_2$ + ... H_2O → ..... $\mathbf{Mn}^{2+}$ + ... $\mathbf{S}O_4^{2-}$ + ... H^+

oxidation numbers: ....

(ii) ..... $\mathbf{Cr}_2O_7^{2-}$ + ... $\mathbf{N}O_2$ + ... H^+ → ..... $\mathbf{Cr}^{3+}$ + ... $\mathbf{N}O_3^-$ + ... H_2O

oxidation numbers: ....

[6]

(d) Outline the role that Fe^{3+} ions play in catalysing the reaction between iodide ions and peroxydisulfate(VI) ions.

$$2I^- + S_2O_8^{2-} \longrightarrow I_2 + 2SO_4^{2-}$$

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.....[2]

[Total: 14]