

# 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%	77.5%	70%	62.5%	57.5%	45%	<45%

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

.....  
 .....

- (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
$\text{OH}^-$		
$\text{NH}_4^+$		
$\text{CH}_3\text{OH}$		
$\text{CH}_3\text{NH}_2$		

[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  $\text{CuSO}_4$  is dissolved in liquid ammonia at  $-33^\circ\text{C}$ , a deep blue solution **C** results.

When 0.2 mol of solid  $\text{NaOH}$  is added to solution **C**, and the ammonia solvent allowed to evaporate, a solid residue is obtained.

Heating this residue to  $200^\circ\text{C}$  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  $\text{BaCl}_2(\text{aq})$  to solution **E** produces a white precipitate **F**.

Solid **D** dissolves in  $\text{HNO}_3(\text{aq})$  on warming, without evolution of gas, to give a pale blue solution containing  $\text{Cu}(\text{NO}_3)_2(\text{aq})$ .

- (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  $\text{HNO}_3(\text{aq})$ .

.....

[5]

- (c) (i)** Describe what you would observe when a solid sample of anhydrous  $\text{Cu}(\text{NO}_3)_2$  is strongly heated.

.....  
.....

- (ii)** Write an equation for this reaction.

.....

[2]

[Total: 10]

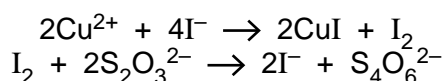
- 2 (a) Explain why complexes of transition elements are often coloured.

.....  
 .....  
 .....  
 .....  
 ..... [3]

- (b) When water is added to white anhydrous  $\text{CuSO}_4$ , the solid dissolves to give a blue solution. The solution changes to a yellow-green colour when concentrated  $\text{NH}_4\text{Cl}(\text{aq})$  is added to it. Concentrating the solution produces green crystals of an ammonium salt with the empirical formula  $\text{CuN}_2\text{H}_8\text{Cl}_4$ . Explain these observations, showing your reasoning.

.....  
 .....  
 .....  
 .....  
 ..... [3]

- (c) Copper can be recovered from low-grade ores by ‘leaching’ the ore with dilute  $\text{H}_2\text{SO}_4$ , which converts the copper compounds in the ore into  $\text{CuSO}_4(\text{aq})$ . 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  $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$ .



When an excess of  $\text{KI}(\text{aq})$  was added to a  $50.0\text{ cm}^3$  sample of leach solution, and the resulting mixture titrated,  $19.5\text{ cm}^3$  of  $0.0200\text{ mol dm}^{-3}$   $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$  were required to discharge the iodine colour. Calculate the  $[\text{Cu}^{2+}(\text{aq})]$ , 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*.

.....  
..... [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.

.....  
.....  
.....  
.....  
.....  
.....  
..... [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 .....

.....

sodium location in organism .....

role .....

.....

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.

.....

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

.....

.....

.....

[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.

.....

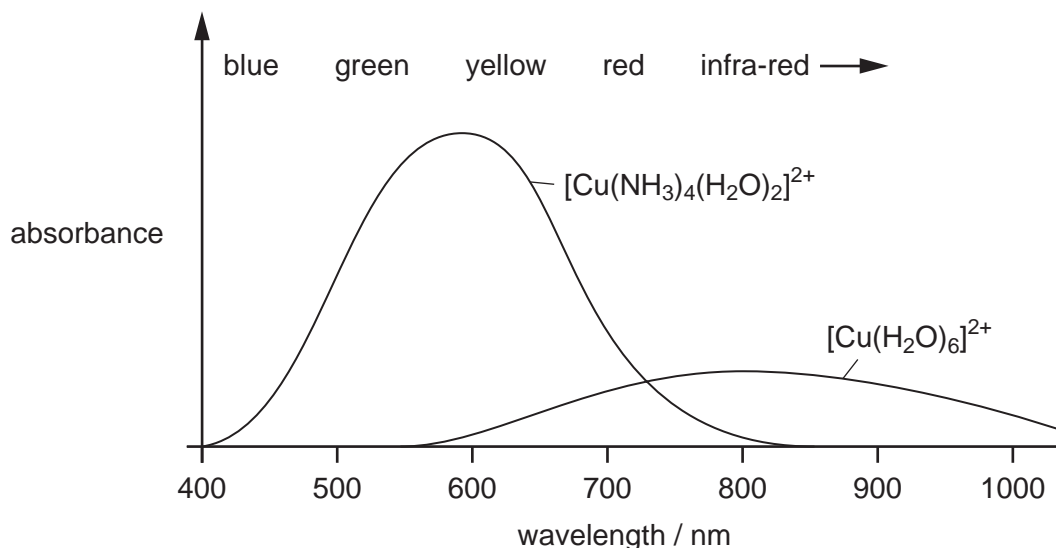
.....

.....

.....

..... [3]

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



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

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

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

(ii) Using the spectra above give **two** reasons why the colour of the  $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$  ion is deeper (more intense) than that of the  $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$  ion.

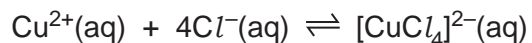
.....

.....

.....

(iii) Predict the absorption spectrum of the complex  $[\text{Cu}(\text{NH}_3)_2(\text{H}_2\text{O})_4]^{2+}$ , and sketch this spectrum on the above graph. [6]

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



(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  $4.2 \times 10^5$ .  
Calculate the  $[\text{CuCl}_4]^{2-}/[\text{Cu}^{2+}]$  ratio when  $[\text{Cl}^{-}] = 0.20 \text{ mol dm}^{-3}$ .

.....

.....

[3]

[Total: 12]



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

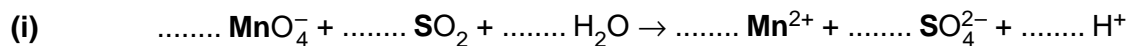
(a) **Apart from its catalytic activity**, state **two** properties of iron or its compounds that show that it is a transition element.

.....  
.....[2]

(b) You are provided with a solution of  $\text{KMnO}_4$  of known concentration in a burette. Outline how you could use this solution to find out the concentration of  $\text{Fe}^{2+}(\text{aq})$  in a solution. You should include relevant equations for any reactions you describe.

.....  
.....  
.....  
.....  
.....  
.....  
.....  
.....  
.....  
.....  
.....[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.



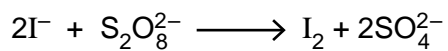
oxidation numbers:  $\dots\dots$   $\dots\dots$   $\dots\dots$   $\dots\dots$



oxidation numbers:  $\dots\dots$   $\dots\dots$   $\dots\dots$   $\dots\dots$

[6]

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



.....

.....

..... [2]

[Total: 14]