Transition elements - 2021

1. Nov/2020/Paper_41/No.5

A solution is made by dissolving $CuSO_4 \cdot 5H_2O$ in an excess of aqueous ammonia. This solution contains the copper complex $[Cu(NH_3)_4]^{2+}$.

(a) (i) Write an expression for the K_{stab} of $[Cu(NH_3)_4]^{2+}$.

K_{stab} =

[1]

(ii) State the colour of the solution of $[Cu(NH_3)_4]^{2+}$.

..... [1]

The solution of $[Cu(NH_3)_4]^{2+}$ is heated gently in a fume cupboard so that NH_3 is released. Some NH_3 remains in solution and some forms NH_3 gas. The colour of the solution changes; a precipitate of $Cu(OH)_2$ forms and is collected.

A sample of $Cu(OH)_2$ is added to concentrated hydrochloric acid. A reaction takes place forming a coloured copper complex, **Y**.

A sample of $Cu(OH)_2$ is added to dilute sulfuric acid. A reaction takes place forming a coloured copper complex, **Z**.

$[Cu(NH_3)_4]^{2+}$, **Y** and **Z** are different colours.

(b) Suggest an equation for the reaction of $[Cu(NH_3)_4]^{2+}$ to form $Cu(OH)_2$ as the aqueous solution of $[Cu(NH_3)_4]^{2+}$ is heated.

..... [1]

(c) Suggest an equation for the reaction of $Cu(OH)_2$ with concentrated hydrochloric acid, forming **Y**.

..... [2]

(d) Complete the table with the colour and geometry of complex **Y** and the colour, geometry and formula of complex **Z**.

	Y	Z
colour of complex		
geometry of complex		
formula of complex		

[2]

(e) Explain why complexes **Y** and **Z** are coloured and why their colours are different.

.....

.....

.....

.....

.....

.....

.....

..... [5]

[Total: 12]

2. Nov/2020/Paper_41/No.6

(a) When 1.0 mol dm^{-3} $Na_2S_2O_3(aq)$ is added to a solution containing $Ag^+(aq)$ ions, a linear complex, **P**, is formed. $S_2O_3^{2-}$ ions are present in **P** as monodentate ligands.

(i) Define the term *monodentate ligand*.

.....

..... [2]

(ii) Give the formula of **P**, including its charge.

..... [1]

(b) When 1.0 mol dm^{-3} NaCN(aq) is added to a solution of **P**, a mixture which includes a second linear complex, **Q**, is formed. In this mixture the concentration of **Q** is much greater than the concentration of **P**.

(i) Write an equation for the reaction that occurs when NaCN(aq) is added to a solution of **P**.

..... [1]

(ii) Suggest a reason why the concentration of **Q** is much greater than the concentration of **P** in the mixture.

.....

.....

..... [1]

(iii) Name the type of reaction in which **P** forms **Q**.

..... [1]

(c) Platinum forms a complex ion with the formula $[Pt(CN)_2Cl_2]^{2-}$. In this complex ion the carbon atom of each CN^- ligand bonds to the platinum ion. This complex shows stereoisomerism.

(i) There are only two isomers of this complex.

Draw structures of these two isomers in the boxes below.

Pt	Pt

[1]

(ii) Describe the geometry of $[Pt(CN)_2Cl_2]^{2-}$.

..... [1]

(iii) Name the type of stereoisomerism shown by $[Pt(CN)_2Cl_2]^{2-}$.

..... [1]

[Total: 9]

3. Nov/2020/Paper_42/No.5

(a) Define the term *transition element*.

.....

..... [1]

(b) (i) Complete the electronic configuration of an isolated gaseous Fe^{3+} ion.

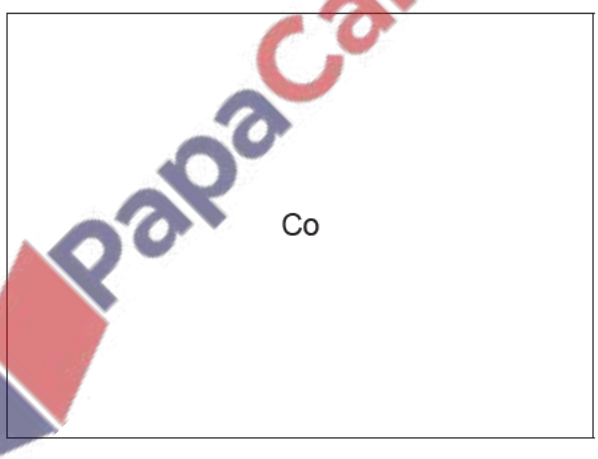
$1s^2$ ..... [1]

(ii) Name **two** transition elements whose isolated gaseous **atoms** have the same number of electrons in the 3d subshell as an isolated gaseous Fe^{3+} ion.

..... [1]

(c) Cobalt(II) sulfate is added to water to form a pink solution containing complex ion **P**. An excess of concentrated hydrochloric acid is added to this solution to form a blue solution containing complex ion **Q**.

(i) Complete the diagram to show the three-dimensional structure of **Q**.
State the charge on this complex ion.



charge .....

[2]

(ii) Name the type of reaction in which **P** forms **Q**.

..... [1]

(iii) Explain why solutions that contain transition element ions are often coloured.

.....

.....

.....

.....

.....

..... [4]

(iv) Explain why the colours of **P** and **Q** are different.

.....

.....

..... [2]

(d) A solution of the bidentate ligand 1,2-diaminoethane, $H_2NCH_2CH_2NH_2$, is added to an aqueous solution of cobalt(II) sulfate. Oxygen is then bubbled into the mixture forming a complex ion with the formula $[Co(H_2NCH_2CH_2NH_2)_3]^{3+}$.

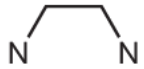
This complex ion exists as a mixture of two isomers. The geometry of both of these isomeric complexes is octahedral.

(i) In this reaction, cobalt undergoes **two** types of reaction. One type of reaction is the same as that described in **(c)(ii)**.

Name the **other** type of reaction that cobalt undergoes.

..... [1]

(ii) Draw the three-dimensional structures of the two isomeric complexes in the boxes.

You may use  to represent a molecule of $H_2NCH_2CH_2NH_2$.

Co	Co

[2]

(iii) Name the type of stereoisomerism shown by these two isomeric complexes.

..... [1]

(iv) State the co-ordination number of cobalt in these two isomeric complexes.

..... [1]

(e) The stability constants, K_{stab}, of three complexes of mercury(II) are given in the table.

complex	K_{stab}
$[Hg(CN)_4]^{2-}$	2.5×10^{41}
$[HgCl_4]^{2-}$	1.7×10^{16}
$[HgI_4]^{2-}$	2.0×10^{30}

(i) Write an expression for the K_{stab} of $[Hg(CN)_4]^{2-}$.

K_{stab} =

[1]

(ii) An aqueous solution containing Hg^{2+} is added to a solution containing equal concentrations of CN^-(aq), Cl^-(aq) and I^-(aq). The mixture is left to reach equilibrium.

Predict which of the complexes $[Hg(CN)_4]^{2-}$, $[HgCl_4]^{2-}$ and $[HgI_4]^{2-}$ is present in the resulting mixture in the highest concentration and which is present in the lowest concentration. Explain your answer.

.....

.....

.....

..... [2]

[Total: 20]

4. March/2020/Paper_42/No.1

Iron is a transition element in the fourth period. Iron forms compounds containing the ions Fe^{2+} and Fe^{3+}.

(a) (i) Define the term *transition element*.

.....

.....

..... [1]

(ii) Compare the melting point and density of iron with those of calcium, an s-block element in the fourth period.

melting point .....

density .....

[1]

(iii) Complete the electronic configuration of an isolated gaseous Fe^{2+} ion.

$1s^2$ ..... [1]

(iv) Aqueous Fe^{3+} ions form coloured complexes.

Explain the origin of the colour in transition element complexes.

.....

.....

.....

.....

.....

..... [4]

(b) When an excess of $CN^-(aq)$ ions is added to green $[Fe(H_2O)_6]^{2+}(aq)$ ions, yellow $[Fe(CN)_6]^{4-}$ complex ions are formed.

Heating $[Fe(CN)_6]^{4-}$ with dilute nitric acid and then neutralising the product with $Na_2CO_3(aq)$ produces red crystals, containing the $[Fe(CN)_5NO]^{2-}$ complex ion.

NO is a neutral, monodentate ligand.

(i) State the shape of the $[Fe(H_2O)_6]^{2+}(aq)$ complex ion.

..... [1]

(ii) Write the equation for the reaction between $[Fe(H_2O)_6]^{2+}(aq)$ ions and an excess of $CN^-(aq)$ ions.

..... [1]

(iii) Deduce the oxidation states of iron in:

$[Fe(CN)_6]^{4-}$ ..... $[Fe(CN)_5NO]^{2-}$ .....
[1]

(iv) Define the term *monodentate ligand*.

.....

..... [2]

(v) Complete the diagram to show the three-dimensional structure of the $[Fe(CN)_5NO]^{2-}$ complex ion.

[1]

(vi) The two complex ions $[Fe(CN)_6]^{4-}$ and $[Fe(CN)_5NO]^{2-}$ are different colours.

Explain why the colours of the two complex ions are different.

.....

.....

..... [2]

(c) **E** is a complex ion, $[Fe(C_2O_4)_2Cl_2]^{4-}$, containing Fe^{2+} with a coordination number of 6.

(i) Define the term *coordination number*.

.....

..... [1]

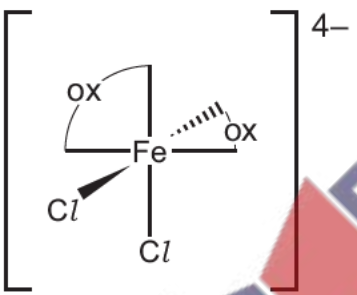
(ii) **E** shows both optical isomerism and *cis-trans* isomerism.

One isomer of **E** is shown. The $C_2O_4^{2-}$ ion is represented as ox.

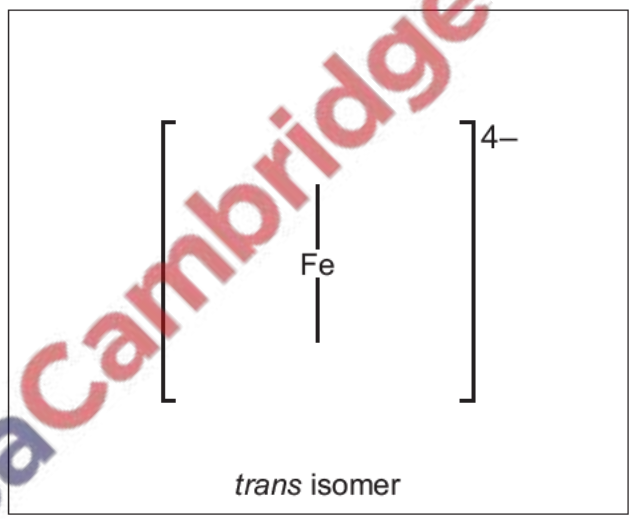
In the boxes, draw three-dimensional diagrams to show:

- the *trans* isomer of **E**
- the optical isomer of **E**.

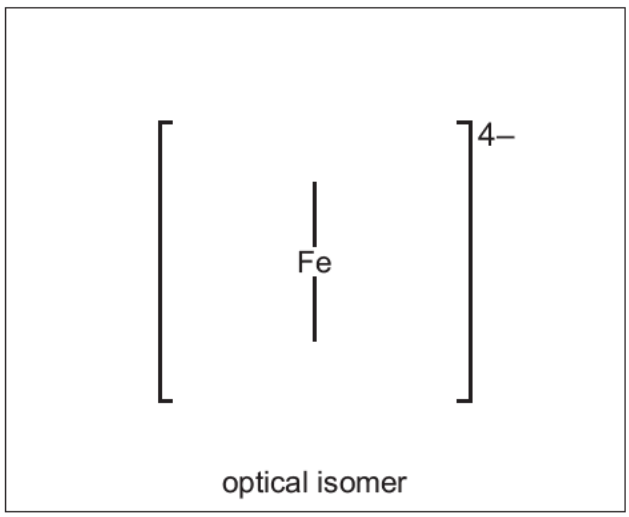
E



cis isomer



trans isomer



optical isomer

[2]

(iii) $[Fe(C_2O_4)_2Cl_2]^{4-}$ contains ligands which are anions of ethanedioic acid, HO_2CCO_2H.

Complete the table to show any observations for the reactions of HO_2CCO_2H with the named reagents.

Where no change is observed, write 'none'.

reagent	observations with HO_2CCO_2H
warm acidified manganate(VII)	
2,4-dinitrophenylhydrazine	
warm Tollens' reagent	

[2]

[Total: 20]

5. June/2020/Paper_41/No.10

(a) The electronic configuration of transition element **Q** is [Ar] $3d^2$ $4s^2$.

Predict the likely oxidation states of element **Q** in compounds.

..... [1]

(b) Suggest why transition elements often show variable oxidation states in their compounds, but typical s-block elements such as calcium do not.

.....

..... [1]

(c) Many enzymes contain transition element complexes.

Describe, with the aid of a suitably labelled diagram, how an enzyme catalyses the breakdown of a substrate molecule.

.....

.....

.....

..... [3]

[Total: 5]

6. June/2020/Paper_42/No.1

$EDTA^{4-}$, is a polydentate ligand.

(a) (i) Explain what is meant by the term *polydentate ligand*.

.....

.....

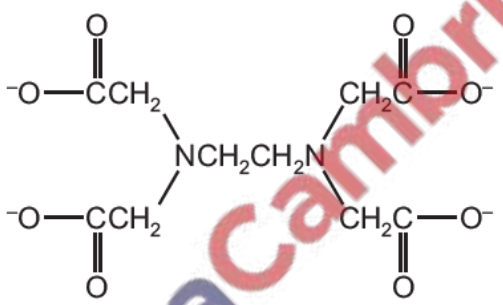
..... [2]

(ii) When a solution containing $EDTA^{4-}$ is added to a solution containing $[Cd(H_2O)_6]^{2+}$ a new complex is formed, $[CdEDTA]^{2-}$.

equilibrium **1** $[Cd(H_2O)_6]^{2+} + EDTA^{4-} \rightleftharpoons [CdEDTA]^{2-} + 6H_2O$

Circle, on the structure of $EDTA^{4-}$, the **six** atoms that form bonds with the metal ion.

$EDTA^{4-}$



[1]

(iii) Write an expression for the stability constant, K_{stab1}, for equilibrium **1**, and state its units.

K_{stab1} =

units = ...

[2]

(b) Cadmium ions form complexes with methylamine, CH_3NH_2, and with 1,2-diaminoethane, $H_2NCH_2CH_2NH_2$, as shown in equilibriums **2** and **3**. 1,2-diaminoethane is shown as en.

equilibrium **2** $[Cd(H_2O)_6]^{2+} + 4CH_3NH_2 \rightleftharpoons [Cd(CH_3NH_2)_4(H_2O)_2]^{2+} + 4H_2O$ $K_{stab2} = 3.60 \times 10^6$

equilibrium **3** $[Cd(H_2O)_6]^{2+} + 2en \rightleftharpoons [Cd(en)_2(H_2O)_2]^{2+} + 4H_2O$ $K_{stab3} = 4.20 \times 10^{10}$

An equilibrium is set up between these two complexes as shown in equilibrium **4**.

equilibrium **4** $[Cd(CH_3NH_2)_4(H_2O)_2]^{2+} + 2en \rightleftharpoons [Cd(en)_2(H_2O)_2]^{2+} + 4CH_3NH_2$ $\Delta H^\ominus = +0.840\,kJ\,mol^{-1}$ $\Delta S^\ominus = +80.9\,J\,K^{-1}\,mol^{-1}$

(i) K_{eq4} is the equilibrium constant for equilibrium **4**.

Write an expression for K_{eq4} in terms of K_{stab2} and K_{stab3}.

K_{eq4} =

[1]

(ii) Calculate the value of the standard Gibbs free energy change, $\Delta G^\ominus$, for equilibrium **4** at 298 K.

$\Delta G^\ominus$ = ... $kJ\,mol^{-1}$ [2]

(iii) State how the value of $\Delta G^\ominus$ changes as the temperature increases. Explain your answer.

.....

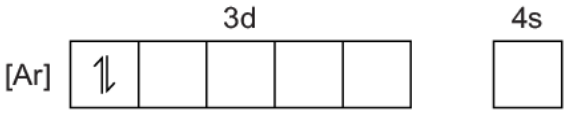
.....

..... [1]

[Total: 9]

7. June/2020/Paper_42/No.3

(a) Complete the electronic configuration of an isolated gaseous nickel(II) ion, Ni^{2+}.



[1]

(b) Explain the origin of colour in transition element complexes.

.....

.....

.....

.....

.....

..... [4]

(c) Hexaaquanickel(II) ions are green. They form a green precipitate with hydroxide ions, OH^-, in equilibrium **1** and a blue complex with ammonia, NH_3, in equilibrium **2**.

equilibrium **1** $[Ni(H_2O)_6]^{2+} + 2OH^- \rightleftharpoons Ni(OH)_2 + 6H_2O$
green ppt.

equilibrium **2** $[Ni(H_2O)_6]^{2+} + 6NH_3 \rightleftharpoons [Ni(NH_3)_6]^{2+} + 6H_2O$
blue

Use Le Chatelier's principle to suggest explanations for the following observations.

(i) Explain why when aqueous NH_3 is added dropwise to $[Ni(H_2O)_6]^{2+}$ a green precipitate is formed.

.....

.....

..... [1]

(ii) Explain why when a large excess of aqueous NH_3 is added to $[Ni(H_2O)_6]^{2+}$, the green precipitate dissolves and a blue solution is formed.

.....

.....

..... [1]

(d) The complex ion $[NiBr_2(CN)_2]^{2-}$ shows stereoisomerism.

Draw diagrams to show the two isomers of $[NiBr_2(CN)_2]^{2-}$. Name the type of stereoisomerism.

isomer 1	isomer 2

type of stereoisomerism .....

[2]

[Total: 9]