

Chapter 9 Coordination Compound

Question 1:

Write the formulas for the following coordination compounds:

- (i) Tetraamminediaquacobalt (III) chloride
- (ii) Potassium tetracyanonickelate(II)
- (iii) Tris(ethane-1,2-diamine) chromium(III) chloride
- (iv) Amminebromidochloridonitrito-N-platinate(II)
- (v) Dichloridobis(ethane-1,2-diamine)platinum(IV) nitrate
- (vi) Iron(III) hexacyanoferrate(II)

Solution 1:

- (i) $[Co(H_2O)(NH_3)_4]Cl_3$
 - (ii) $K_2[Ni(CN)_4]$
 - (iii) $[Cr(en)_3]Cl_3$
 - (iv) $[Pt(NH_3)BrCl(NO_2)]$
 - (v) $[PtCl_2(en)_2(NO_3)_2]$
 - (vi) $Fe_4[Fe(CN)_6]_3$
-

Question 2:

Write the IUPAC names of the following coordination compounds:

- (i) $[Co(NH_3)_8]Cl_3$
- (ii) $[Co(NH_3)_6Cl]Cl_3$
- (iii) $K_3[Fe(CN)_8]$
- (iv) $K_3[Fe(C_2N_4)_3]$
- (v) $K_2[PdCl_4]$
- (vi) $[Pt(NH_3)_2Cl(NH_2CH_3)]Cl$

Solution 2:

- (i) Hexaamminecobalt(III) chloride
 - (ii) Pentaamminechloridocobalt (III) chloride
 - (iii) Potassium hexacyanoferrate(III)
 - (iv) Potassium trioxalatoferrate(III)
 - (v) Potassium tetrachloridopalladate(II)
 - (vi) Diamminechlorido(methylamine)platinum(II) chloride
-

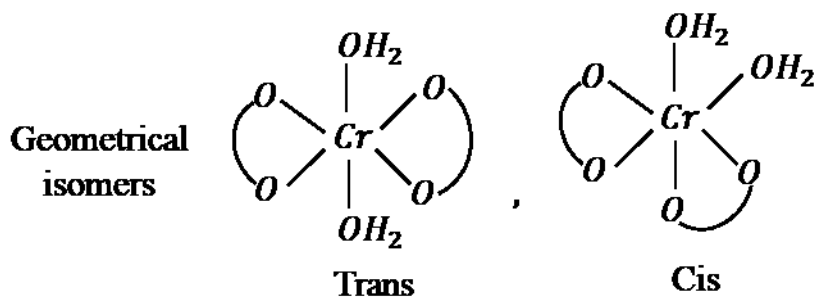
Question 3:

Indicate the types of isomerism exhibited by the following complexes and draw the structures for these isomers:

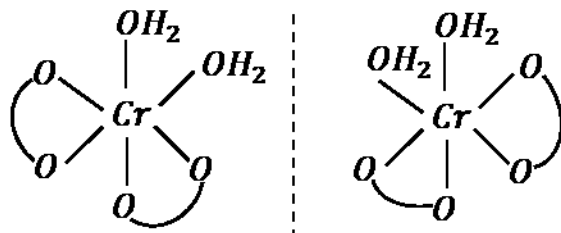
- (i) $K[Cr(H_2O)_2(C_2O_4)_2]$
 (ii) $[Co(en)_2]Cl_2$
 (iii) $[Co(NH_3)_6(NO_2)](NO_3)_2$
 (iv) $[Pt(NH_2)(H_2O)Cl_2]$

Solution 3:

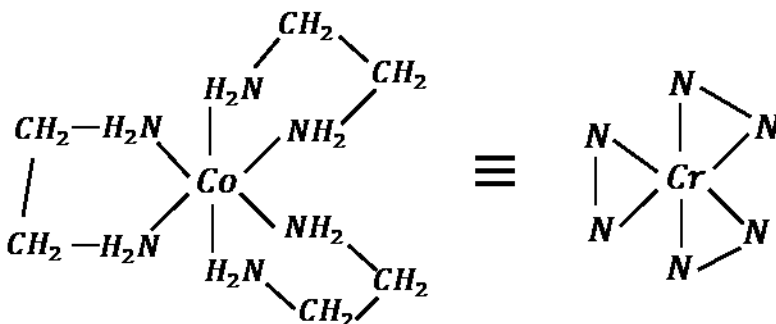
(i) Both geometrical (*cis*-, *trans*-) isomers for $K[Cr(H_2O)_2(C_2O_4)_2]$ can exist. Also, optical isomers for *cis*-isomer exist.



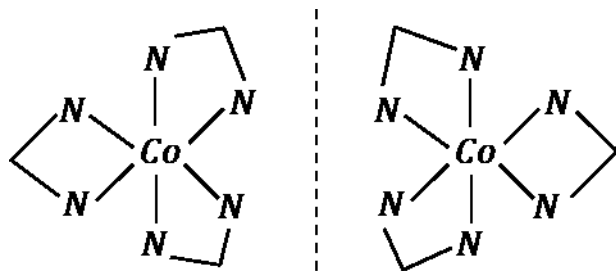
Trans-isomer is optically inactive. On the other hand, *cis*-isomer is optically active.



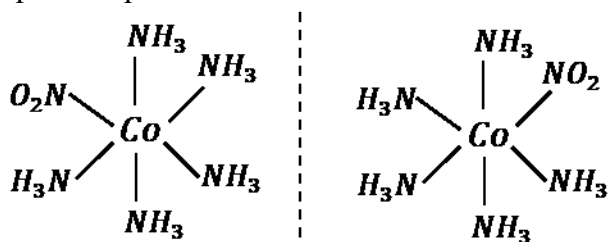
(ii) Two optical isomers for $[Co(en)_2]Cl_2$ exist.



Two optical isomers are possible for this structure.



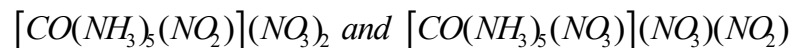
A pair of optical isomers:



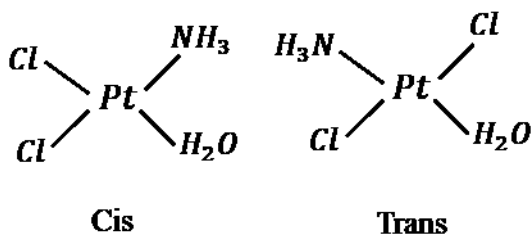
It can also show linkage isomerism. 9741621450



It can also show ionization isomerism.



(iv) Geometrical (*cis*-, *trans*-) isomers of $[Pt(NH_3)(H_2O)Cl_2]$ can exist.

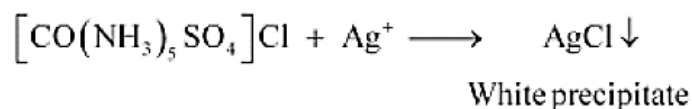
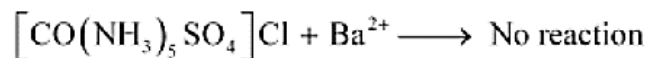
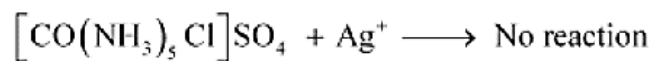
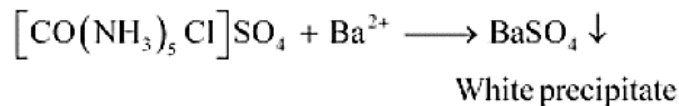


Question 4:

Give evidence that $[Co(NH_3)_5Cl]SO_4$ and $[Co(NH_3)_5SO_4]Cl$ are ionization isomers.

Solution 4:

When ionization isomers are dissolved in water, they ionize to give different ions. These ions then react differently with different reagents to give different products.

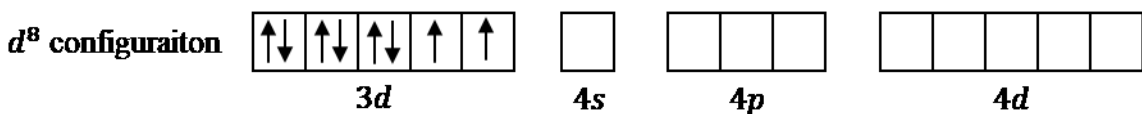


Question 5:

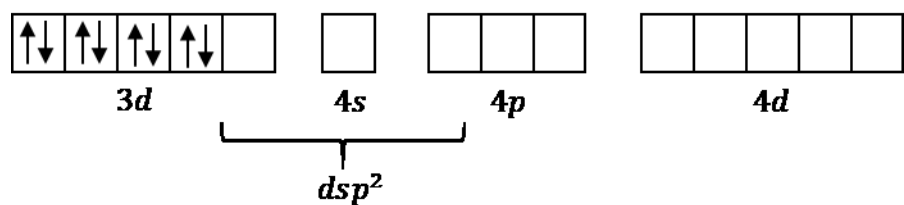
Explain on the basis of valence bond theory that $[\text{Ni}(\text{CN})_4]^{2-}$ ion with square planer structure is diamagnetic and the $[\text{Ni}(\text{Cl})_4]^{2-}$ ion with tetrahedral geometry is paramagnetic.

Solution 5:

Ni is in the +2 oxidation state i.e., in d^8 configuration.

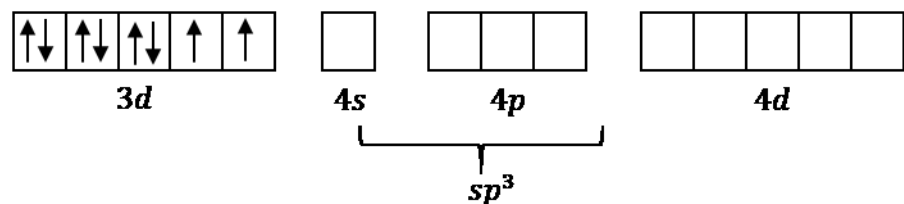


There are 4 CN^- ions. Thus, it can either have a tetrahedral geometry or square planar geometry. Since CN^- ion is a strong field ligand, it causes the pairing of unpaired $3d$ electrons.



It now undergoes dsp^2 hybridization. Since all electrons are paired, it is diamagnetic. In case of $[\text{NiCl}_4]^{2-}$, Cl^- ion is a weak field ligand. Therefore, it does not lead to the pairing of unpaired $3d$ electrons.

Therefore, it undergoes sp^3 hybridization.



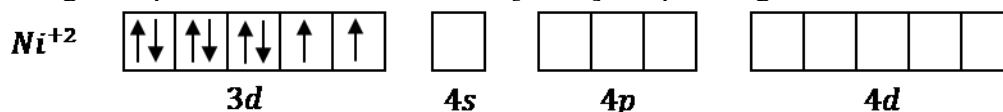
Since there are 2 unpaired electrons in this case, it is paramagnetic in nature.

Question 6:

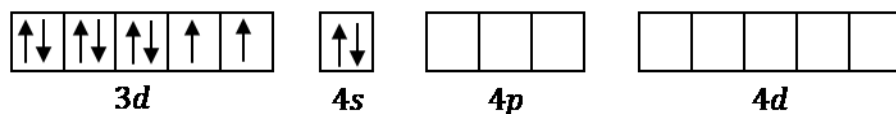
$[NiCl_4]^{2-}$ is paramagnetic while $[Ni(CO)_4]$ is diamagnetic though both are tetrahedral. Why?

Solution 6:

Though both $[NiCl_4]^{2-}$ and $[Ni(CO)_4]$ are tetrahedral, their magnetic characters are different. This is due to a difference in the nature of ligands. Cl^- is a weak field ligand and it does not cause the pairing of unpaired 3d electrons. Hence, $[NiCl_4]^{2-}$ is paramagnetic.



In $[Ni(CO)_4]$, Ni is in the zero oxidation state i.e., it has a configuration of $3d^8 4s^2$.



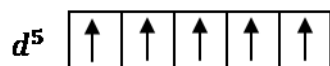
But CO is a strong field ligand. Therefore, it causes the pairing of unpaired 3d electrons. Also, it causes the 4s electrons to shift to the 3d orbital, thereby giving rise to sp^3 hybridization. Since no unpaired electrons are present in this case, $[Ni(CO)_4]$ is diamagnetic.

Question 7:

$[Fe(H_2O)_6]^{3+}$ is strongly paramagnetic whereas $[Fe(CN)_6]^{3+}$ is weakly paramagnetic. Explain.

Solution 7:

In both $[Fe(H_2O)_6]^{3+}$ and $[Fe(CN)_6]^{3+}$, Fe exists in the +3 oxidation state i.e., in d^5 configuration



Since CN^- is a strong field ligand, it causes the pairing of unpaired electrons. Therefore, there is only one unpaired electron left in the d-orbital.



Therefore magnetic moment is given by,

$$\begin{aligned}
 \mu &= \sqrt{n(n+2)} \\
 &= \sqrt{1(1+2)} \\
 &= \sqrt{3} \\
 &= 1.732BM
 \end{aligned}$$

Chapter 9 Coordination Compound

On the other hand, H_2O is a weak field ligand. Therefore, it cannot cause the pairing of electrons. This means that the number of unpaired electrons is 5.

Therefore, magnetic moment is given by,

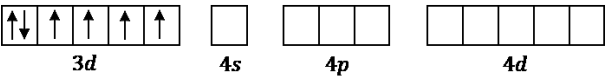
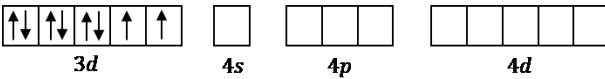
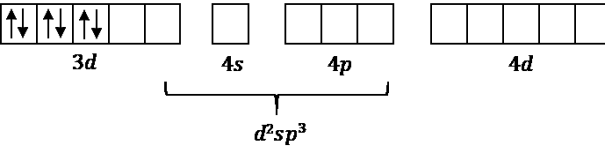
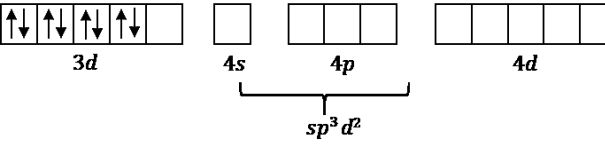
$$\begin{aligned}\mu &= \sqrt{n(n+2)} \\ &= \sqrt{5(5+2)} \\ &= \sqrt{35} \\ &= 5.91BM\end{aligned}$$

Thus, it is evident that $[Fe(H_2O)_6]^{3+}$ is strongly paramagnetic, while $[Fe(CN)_6]^{3+}$ is weakly paramagnetic

Question 8:

Explain $[Co(NH_3)_6]^{3+}$ is an inner orbital complex whereas $[Ni(NH_3)_6]^{2+}$ is an outer orbital complex.

Solution 8:

| $[Co(NH_3)_6]^{3+}$ | $[Ni(NH_3)_6]^{2+}$ |
|--|--|
| Oxidation state of cobalt = +3 | Oxidation state of Ni = +2 |
| Electronic configuration of cobalt = d^6 | Electronic configuration of nickel = d^8 |
|  |  |
| <p>NH_3 being a strong field ligand causes the pairing. Therefore, Cobalt can undergo d^2sp^3 hybridization.</p>  | <p>If NH_3 causes the pairing, then only one $3d$ orbital is empty. Thus, it cannot undergo d^2sp^3 hybridization. So in this complex NH_3 acts as weak field ligand. Therefore, it undergoes sp^3d^2 hybridization.</p>  |
| Hence, it is an inner orbital complex. | Hence, it forms an outer orbital complex. |

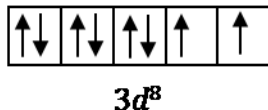
Question 9:

Predict the number of unpaired electrons in the square planar $[Pt(CN_4)]^{2-}$ ion.

Solution 9:



In this complex, Pt is in the +2 state. It forms a square planar structure. This means that it undergoes dsp^2 hybridization. Now, the electronic configuration $Pd (+2)$ of is $5d^8$.



CN^- being a strong field ligand causes the pairing of unpaired electrons. Hence, there are no unpaired electrons in $[Pt(CN)_4]^{2-}$.

Question 10:

The hexaquo manganese (II) ion contains five unpaired electrons, while the hexacyanoion contains only one unpaired electron. Explain using Crystal Field Theory.

Solution 10:

| $[Mn(H_2O)_6]^{2+}$ | $[Mn(CN)_6]^{4-}$ |
|--|---|
| Mn is in the +2 oxidation state. | Mn is in the +2 oxidation state |
| The electronic configuration is d^5 . | The electronic configuration is d^5 . |
| The crystal field is octahedral. Water is a weak field ligand. Therefore, the arrangement of the electrons in $[Mn(H_2O)_6]^{2+}$ is $t_2g^3e_g^2$. | The crystal field is octahedral. Cyanide is a strong field ligand and hence force pairing occurs. Therefore, the arrangement of the electrons in $[Mn(CN)_6]^{4-}$ is $t_2g^5e_g^0$. |

Hence, hexaquo manganese (II) ion has five unpaired electrons, while hexacyano ion has only one unpaired electron.

Question 11:

Calculate the overall complex dissociation equilibrium constant for the $Cu(NH_3)_4^{2+}$ ion, given that β_4 for this complex is 2.1×10^{13} .

Solution 11:

The overall complex dissociation equilibrium constant is the reciprocal of the overall stability constant ,

$$\frac{1}{\beta_4} = \frac{1}{2.1 \times 10^{13}}$$

$$\therefore = 4.7 \times 10^{-14}$$

Chapter 9 Coordination Compound

NCERT Exercise

Question 1:

Explain the bonding in coordination compounds in terms of Werner's postulates.

Solution 1:

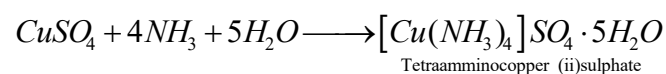
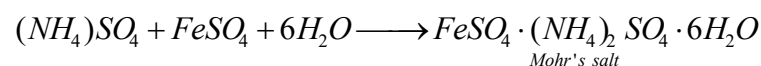
Werner's theory is the first theory to explain the nature of bonding in coordination compounds. The main postulates of this theory are:

- (i) In coordination compound metals exhibits two types of valencies namely, primary and secondary valencies.
 - ii) Primary valencies are satisfied by negative ions and these ions are ionisable. It is represented by dotted line
 - iii) The primary valency corresponds to the oxidation number of the metal ion.
 - iii) Secondary valencies are non ionisable and satisfied by both negative and neutral ions. It is represented through solid line.
 - iv) The secondary valency refers to the coordination number of the metal ion.
 - (v) These valencies project in a specific direction in the space assigned to the definite geometry of the coordination compound.
-

Question 2:

$FeSO_4$ solution mixed with $(NH_4)_2SO_4$ solution in 1:1 molar ratio gives the test of Fe^{2+} ion but $CuSO_4$ solution mixed with aqueous ammonia in 1:4 molar ratio does not give the test of Cu^{2+} ion. Explain why?

Solution 2:



Both the compounds i.e. $FeSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O$ and $[Cu(NH_3)_4]SO_4 \cdot 5H_2O$ fall under the category of addition compounds with only one major difference i.e., the former is an example of a double salt, while the latter is a coordination compound.

A double salt is an addition compound that is stable in the solid state but that which breaks up into its constituent ions in the dissolved state. These compounds exhibit individual properties of their constituents. For e.g. $FeSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O$ breaks into Fe^{2+} , NH_4^+ and SO_4^{2-} ions.

Hence, it gives a positive test for Fe^{2+} ions.

A coordination compound is an addition compound which retains its identity in the solid as well as in the dissolved state. However, the individual properties of the constituents are lost.

This happens because $[Cu(NH_3)_4]SO_4 \cdot 5H_2O$ does not show the test for Cu^{2+} . The ions present in the solution of $[Cu(NH_3)_4]SO_4 \cdot 5H_2O$ are $[Cu(NH_3)_4]^{2+}$ and SO_4^{2-} .

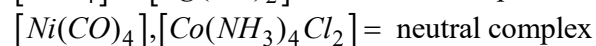
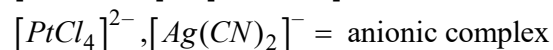
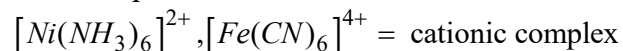
Question 3:

Explain with two examples each of the following: coordination entity, ligand, coordination number, coordination polyhedron, homoleptic and heteroleptic.

Solution 3:**(i) Coordination entity:**

A coordination entity constitutes a central metal atom or ion bonded to a fixed number of ions or molecules called ligands

For example:

**(ii) Ligands**

The neutral molecules or negatively charged ions that surround the metal atom in a coordination entity or a coordinational complex are known as ligands. For example, $\ddot{N}H_3$ Ligands are usually polar in nature and possess at least one unshared pair of valence electrons.

(iii) Coordination number:

The total number of ligands (either neutral molecules or negative ions) that get attached to the central metal atom in the coordination sphere is called the coordination number of the central metal atom. It is also referred to as its ligancy.

For example:

(a) In the complex, $K_2[PtCl_6]$, there are six chloride ions attached to Pt in the coordination sphere.

Therefore, the coordination number of Pt is 6.

(b) Similarly, in the complex $[Ni(NH_3)_4]Cl_2$, the coordination number of the central atom (Ni) is

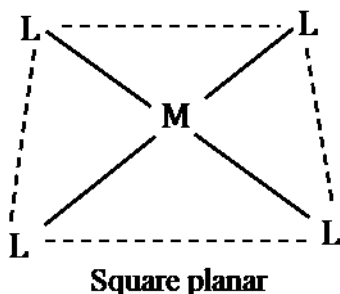
4.

(vi) Coordination polyhedron:

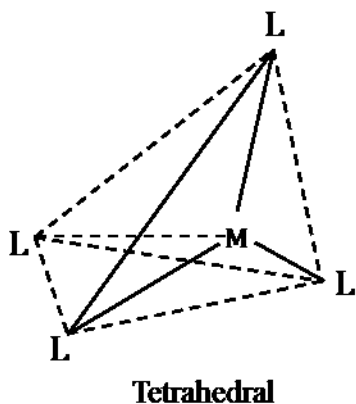
Coordination polyhedrons about the central atom can be defined as the spatial arrangement of the ligands that are directly attached to the central metal ion in the coordination sphere.

For example:

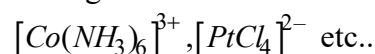
(a)



(b) Tetrahedral

**(v) Homoleptic complexes:**

These are those complexes in which the metal ion is bound to only one kind of a donor group. For e.g.:

**(vi) Heteroleptic complexes:**

Heteroleptic complexes are those complexes where the central metal ion is bound to more than one type of a donor group. For e.g., $[Co(NH_3)_4Cl_2]^+$, $[Co(NH_3)_5Cl]^{2+}$

Question 4:

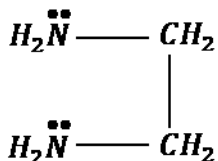
What is meant by unidentate, didentate and ambidentate ligands? Give two examples for each.

Solution 4:

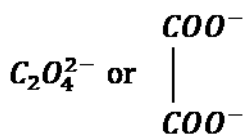
A ligand may contain one or more unshared pairs of electrons which are called the donor sites of ligands. Now, depending on the number of these donor sites, ligands can be classified as follows:

(a) **Unidentate ligands:** Ligands with only one donor sites are called unidentate ligands. For e.g., i etc.

(b) **Didentate ligands:** Ligands that have two donor sites are called didentate ligands. For e.g.,
 (a) Ethane-1,2-diamine



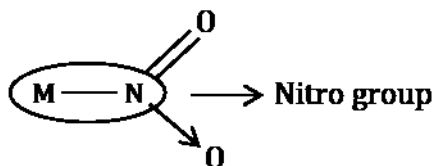
(b) Oxalate ion



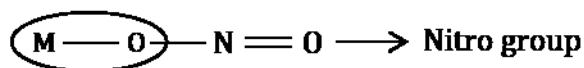
(b) **Ambidentate ligands:**

Ligands that can attach themselves to the central metal atom through two different atoms are called ambidentate ligands. For example:

(a)

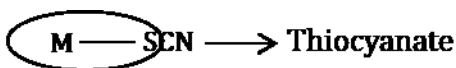


[The donor atom is N]

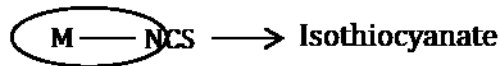


[The donor atom is oxygen]

(b)



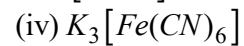
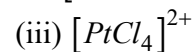
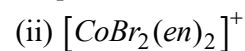
[The donor atom is S]



[The donor atom is N]

Question 5:

Specify the oxidation numbers of the metals in the following coordination entities:

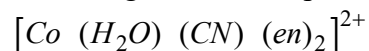


Solution 5:



Let the oxidation number of Co be x .

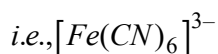
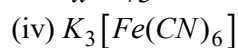
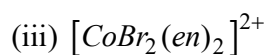
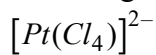
The charge on the complex is +2.



$$x + 0 + (-1) + 2(0) = +2$$

$$x - 1 = +2$$

$$x = +3$$

Let the oxidation number of Pt be x .The charge on the complex is -2 .**Question 6:**

Using IUPAC norms write the formulas for the following:

- (i) Tetrahydroxozincate(II)
- (ii) Potassium tetrachloridopalladate(II)
- (iii) Diamminedichloridoplatinum(II)
- (iv) Potassium tetracyanonickelate(II)
- (v) pentaamminenitrito-O-cobalt(III)
- (vi) Hexaamminecobalt(III)sulphate
- (vii) Potassium tri(oxalato)chromate(III)
- (viii) Hexaammineplatinum(IV)
- (ix) Tetrabromidocuprate(II)
- (x) Pentaamminenitrito-N-cobalt(III)

Solution 6:

- (i) $[Zn(OH)_4]^{2-}$
 - (ii) $K_2 [PdCl_4]$
 - (iii) $[Pt(NH_3)_2 Cl_2]$
 - (iv) $K_2 [Ni(CN)_4]$
 - (v) $[Co(NH_3)_5(ONO)]^{2+}$
 - (vi) $[Co(NH_3)_6]_2 (SO_4)_3$
 - (vii) $K_3 [Cr(C_2O_4)_3]$
 - (viii) $[Pt(NH_3)_6]^{4+}$
 - (ix) $[Cu(Br)_4]^{2+}$
 - (x) $[Co(NH_3)_5(NO_2)]^{2+}$
-

Question 7:

Using IUPAC norms write the systematic names of the following:

- (i) $[Co(NH_3)_6]Cl_3$
- (ii) $[Pt(NH_3)_2 Cl(NH_2CH_3)]Cl$
- (iii) $[Ti(H_2O)_6]^{3+}$
- (iv) $[Co(NH_3)_4 Cl(NO_2)]Cl$
- (v) $[Mn(H_2O)_6]^{2+}$
- (vi) $[NiCl_4]^{2-}$
- (vii) $[Ni(NH_3)_6]Cl_2$
- (viii) $[Co(en)_3]^{3+}$
- (ix) $[Ni(CO)_4]$

Solution 7:

- (a) Hexaamminecobalt(III) chloride
 - (b) Diamminechlorido(methylamine)platinum(II) chloride
 - (c) Hexaqua-titanium(III) ion
 - (d) Tetraamminichloridonitrito-N-Cobalt(III) chloride
 - (e) Hexaqua-manganese(II) ion
 - (f) Tetrachloridonickelate(II) ion
 - (g) Hexaamminenickel(II) chloride
 - (h) Tris(ethane-1, 2-diammine) cobalt(III) ion
 - (i) Tetracarbonylnickel(0)
-

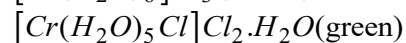
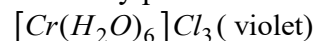
Question 8:

List various types of isomerism possible for coordination compounds, giving an example of each.

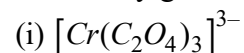
Solution 8:

(f) Solvate isomerism:

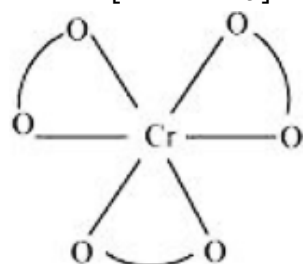
Solvate isomers differ by whether or not the solvent molecule is directly bonded to the metal ion or merely present as a free solvent molecule in the crystal lattice.

**Question 9:**

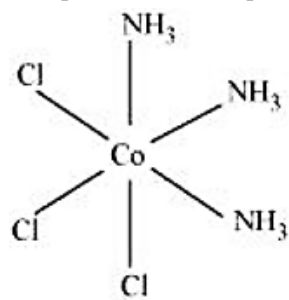
How many geometrical isomers are possible in the following coordination entities?

**Solution 9:**

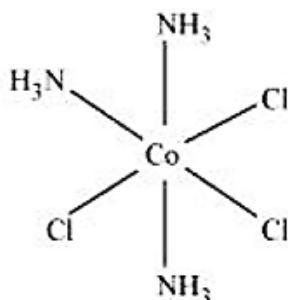
(i) For $[Cr(C_2O_4)_3]^{3-}$, no geometrical isomer is possible as it is a bidentate ligand.



(ii) $[Co(NH_3)_3Cl_3]$ Two geometrical isomers are possible.



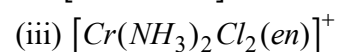
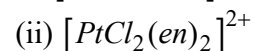
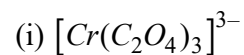
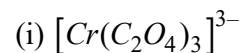
Facial



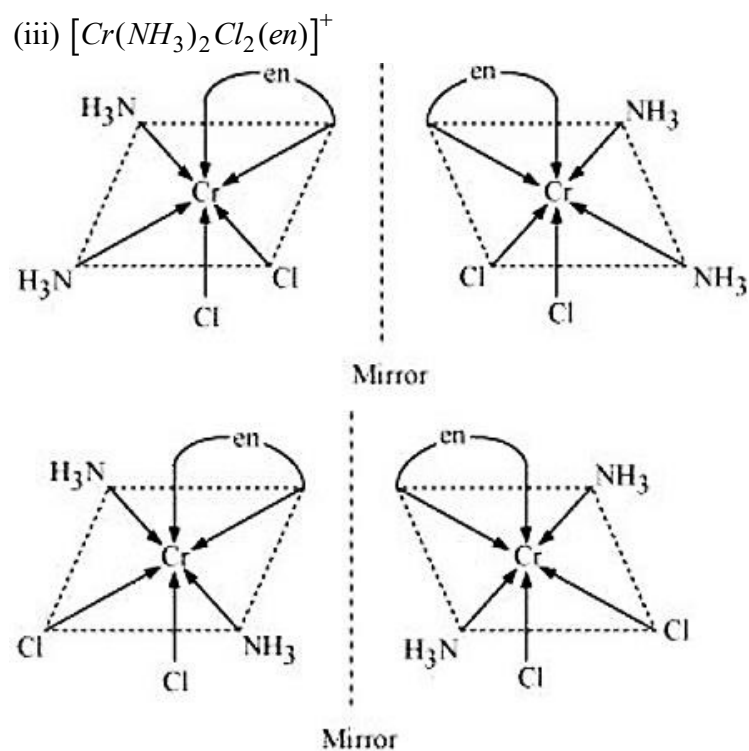
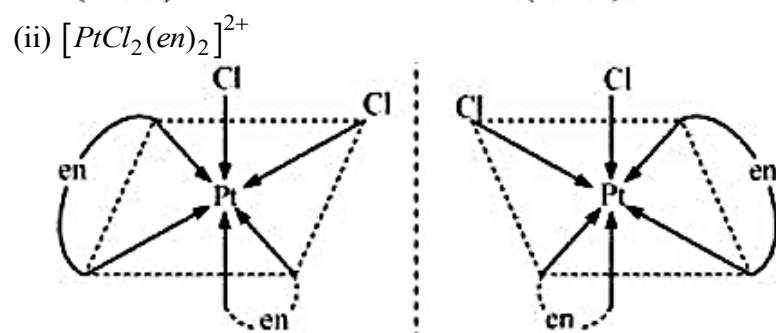
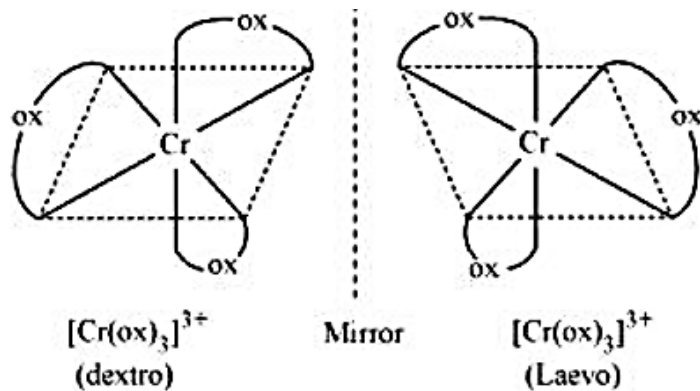
Meridional

Question 10:

Draw the structures of optical isomers of:

**Solution 10:**

Chapter 9 Coordination Compound



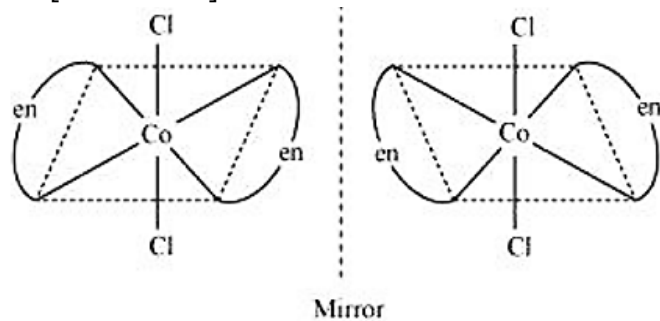
Question 11:

Draw all the isomers (geometrical and optical) of:

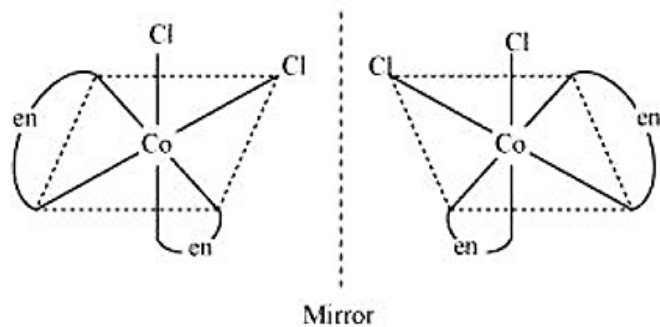
- (i) $[\text{CoCl}_2(\text{en})_2]^+$
- (ii) $[\text{Co}(\text{NH}_3)\text{Cl}(\text{en})_2]^{2+}$
- (iii) $[\text{Cr}(\text{NH}_3)_2\text{Cl}_2(\text{en})]^+$

Solution 11:

- (i) $[\text{CoCl}_2(\text{en})_2]^+$



Trans $[\text{CoCl}_2(\text{en})_2]^+$ isomer-optically inactive
(Superimposable mirror images)

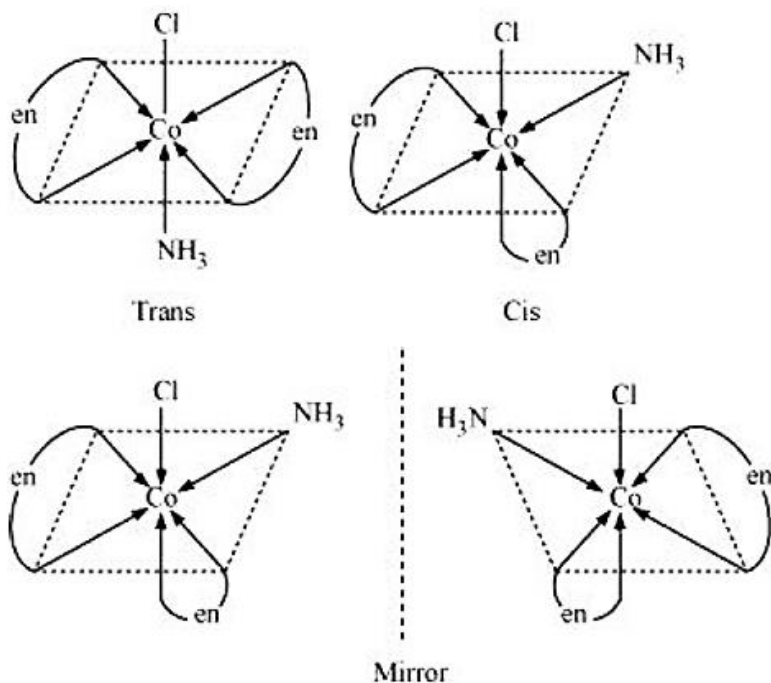


Cis $[\text{CoCl}_2(\text{en})_2]^+$ isomer-optically active
(Non-superimposable mirror images)

In total, three isomers are possible.

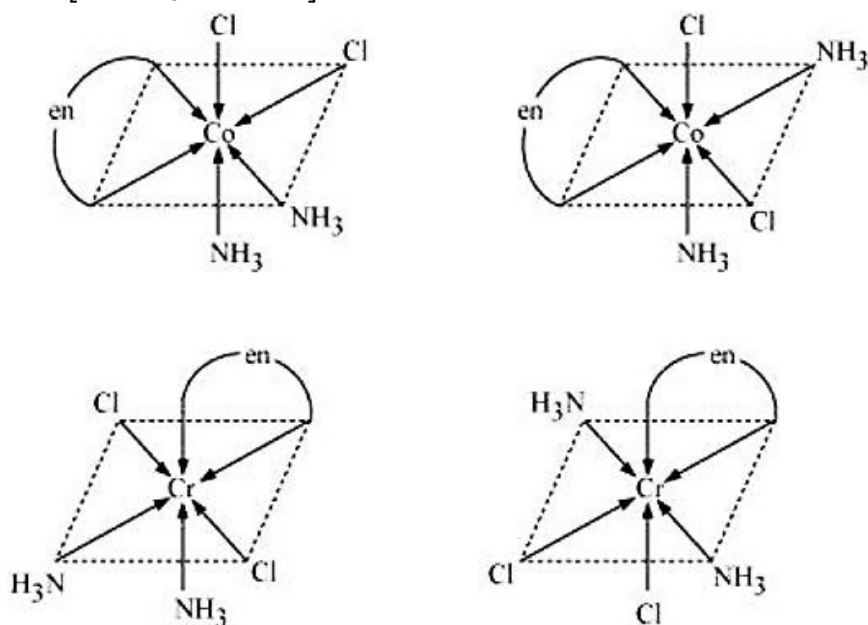
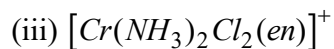
- (ii) $[\text{Co}(\text{NH}_3)\text{Cl}(\text{en})_2]^{2+}$

Chapter 9 Coordination Compound



Trans-isomers are optically inactive.

Cis-isomers are optically active.

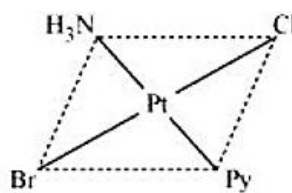
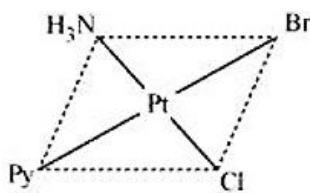
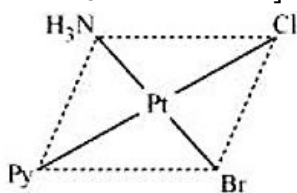
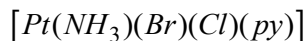


Question 12:

Write all the geometrical isomers of $[Pt(NH_3)(Br)(Cl)(py)]$ and how many of these will exhibit optical isomers?

Solution 12:

Chapter 9 Coordination Compound



From the above isomers, none will exhibit optical isomers. Tetrahedral complexes rarely show optical isomerization. They do so only in the presence of unsymmetrical chelating agents.

Question 13:

Aqueous copper sulphate solution (blue in colour) gives:

- (i) a green precipitate with aqueous potassium fluoride, and
- (ii) a bright green solution with aqueous potassium chloride

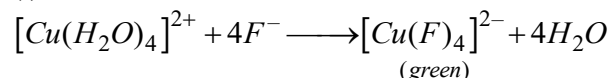
Explain these experimental results.

Solution 13:

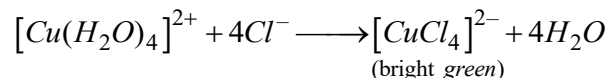
Aqueous $CuSO_4$ exists as $[Cu(H_2O)_4]SO_4$. It is blue in colour due to the presence of

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

(i) When KF is added:



(ii) When KCl is added:

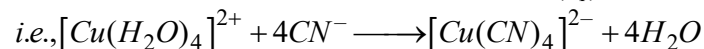
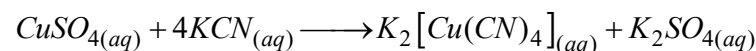


In both these cases, the weak field ligand water is replaced by the F^- and Cl^- ions.

Question 14:

What is the coordination entity formed when excess of aqueous KCN is added to an aqueous solution of copper sulphate? Why is it that no precipitate of copper sulphide is obtained when $H_2S(g)$ is passed through this solution?

Solution 14:



Thus, the coordination entity formed in the process is $K_2[Cu(CN)_4]$, is a very stable complex, which does not ionize to give Cu^{2+} ions when added to water. Hence, Cu^{2+} ions are not precipitated when $H_2S(g)$ is passed through the solution.

Question 15:

Discuss the nature of bonding in the following coordination entities on the basis of valence bond theory:

- (i) $[Fe(CN)_6]^{4-}$
 (ii) $[FeF_6]^{3-}$
 (iii) $[Co(C_2O_4)_3]^{3-}$
 (iv) $[CoF_6]^{3-}$

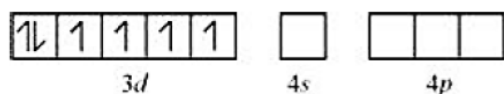
Solution 15:

- (i) $[Fe(CN)_6]^{4-}$

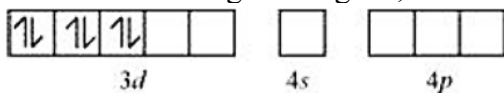
In the above coordination complex, iron exists in the +II oxidation state.

Fe^{2+} : Electronic configuration is $3d^6$

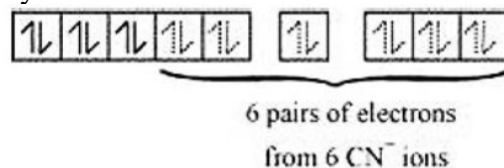
Orbitals of Fe^{2+} ion.



As CN^- is a strong field ligand, it causes the pairing of the unpaired 3d electrons.



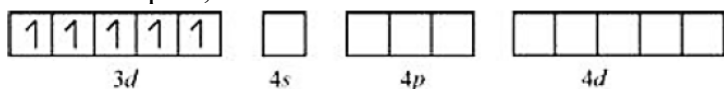
Since there are six ligands around the central metal ion, the most feasible hybridization is d^2sp^3 hybridized orbitals of Fe^{2+} are:



Hence, the geometry of the complex is octahedral and the complex is diamagnetic (as there are no unpaired electrons).

- (ii) $[FeF_6]^{3-}$

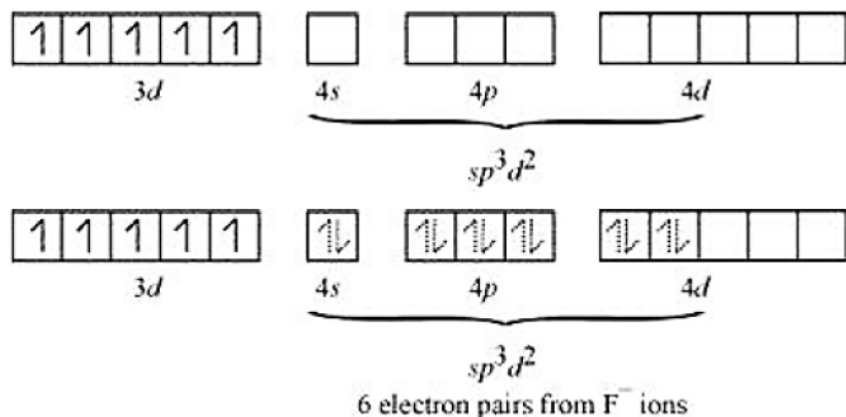
In this complex, the oxidation state of Fe is +3.



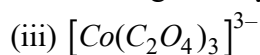
There are 6 F^- ions. Thus, it will undergo d^2sp^3 and sp^3d^2 hybridization. As F^- is a weak field ligand, it does not cause the pairing of the electrons in the 3d orbital. Hence, the most feasible hybridization is sp^3d^2 .

sp^3d^2 hybridized orbitals of Fe are:

Chapter 9 Coordination Compound

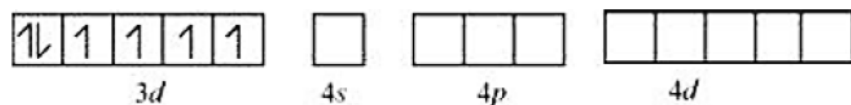


Hence, the geometry of the complex is found to be octahedral.



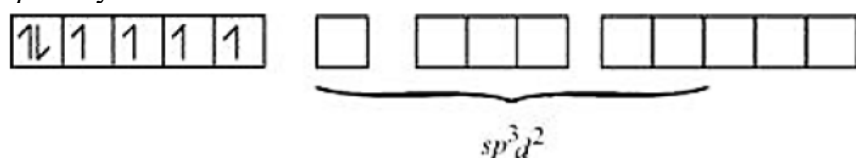
Cobalt exists in the +3 oxidation state in the given complex.

Orbitals of Co^{3+} ion:

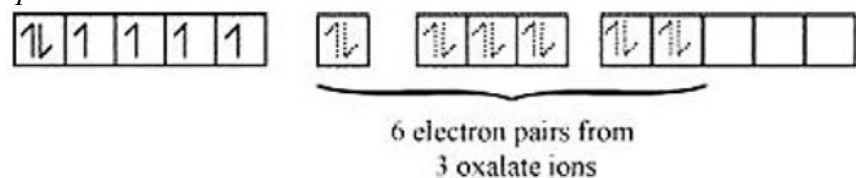


Oxalate is a weak field ligand. Therefore, it cannot cause the pairing of the 3d orbital electrons. As there are 6 ligands, hybridization has to be either sp^3d^2 and d^2sp^3 hybridization.

sp^3d^2 hybridization of Co^{3+}



The 6 electron pairs from the 3 oxalate ions (oxalate anion is a bidentate ligand) occupy these sp^3d^2 orbitals.

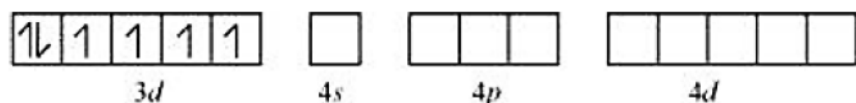


Hence, the geometry of the complex is found to be octahedral.



Cobalt exists in the +3 oxidation state.

Orbitals of Co^{3+} ion:



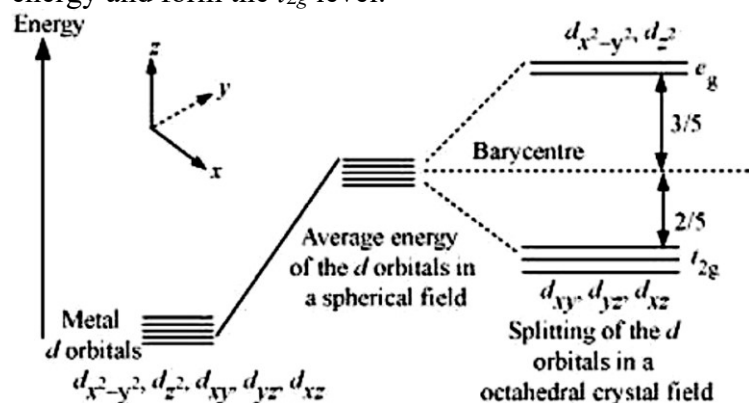
Again, fluoride ion is a weak field ligand. It cannot cause the pairing of the 3d electrons. As a result, the Co^{3+} ion will undergo sp^3d^2 hybridization. sp^3d^2 hybridized orbitals of Co^{3+} ion are.

Question 16:

Draw figure to show the splitting of d orbitals in an octahedral crystal field.

Solution 16:

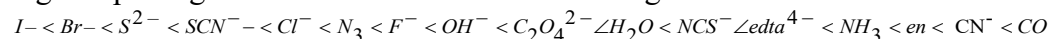
The splitting of the d orbitals in an octahedral field takes place in such a way that $d_{x^2-y^2}, d_{z^2}$ experience a rise in energy and form the e_g level, while d_{yz}, d_{yz} and d_{zx} experience a fall in energy and form the t_{2g} level.

**Question 17:**

What is spectrochemical series? Explain the difference between a weak field ligand and a strong field ligand.

Solution 17:

A spectrochemical series is the arrangement of common ligands in the increasing order of their crystal-field splitting energy (CFSE) values. The ligands present on the R.H.S of the series are strong field ligands while that on the L.H.S are weak field ligands. Strong field ligands cause higher splitting in the d orbitals than weak field ligands.

**Question 18:**

What is crystal field splitting energy? How does the magnitude of Δ_o decide the actual configuration of d orbitals in a coordination entity?

Solution 18:

The degenerate d -orbitals (in a spherical field environment) split into two levels i.e., e_g and t_{2g} in the presence of ligands. The splitting of the degenerate levels due to the presence of ligands is called the crystal-field splitting while the energy difference between the two levels (e_g and t_{2g}) is called the crystal-field splitting energy. It is denoted by Δ_o .

After the orbitals have split, the filling of the electrons takes place. After 1 electron (each) has been filled in the three t_{2g} orbitals, the filling of the fourth electron takes place in two ways. It can enter the e_g orbital (giving rise to $t_{2g}^3 e_g^1$ like electronic configuration) or the pairing of the electrons can take place in the t_{2g} orbitals (giving rise to $t_{2g}^4 e_g^0$ like electronic configuration). If the Δ_o value of a ligand is less than the pairing energy (P), then the electrons enter the e_g orbital.

On the other hand, if the Δ_o value of a ligand is more than the pairing energy (P), then the electrons enter the t_{2g} orbital.

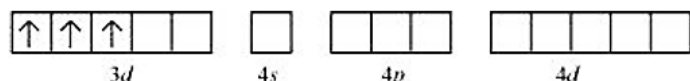
Question 19:

$[Cr(NH_3)_6]^{3+}$ is paramagnetic while $[Ni(CN)_4]^{2-}$ is diamagnetic. Explain why?

Solution 19:

Cr is in the +3 oxidation state i.e., d^3 configuration. Also, is a weak field ligand that does not cause the pairing of the electrons in the 3d orbital.

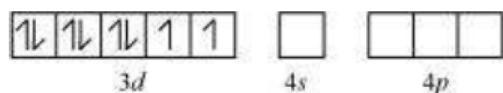
Cr³⁺



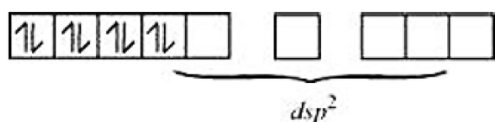
Therefore, it undergoes d^2sp^3 hybridization and the electrons in the 3d orbitals remain unpaired. Hence, it is paramagnetic in nature.

In $[Ni(CN)_4]^{2-}$ Ni exists in the +2 oxidation state i.e., d^8 configuration.

Ni²⁺



CN^- is a strong field ligand. It causes the pairing of the 3d orbital electrons. Then, Ni^{2+} undergoes dsp^2 hybridization.



As there are no unpaired electrons, it is diamagnetic.

Question 20:

A solution of $[Ni(H_2O)_6]^{2+}$ is green but a solution of $[Ni(CN)_4]^{2-}$ is colourless. Explain.

Solution 20:

$[Ni(H_2O)_6]^{2+}$, H_2O is a weak field ligand. Therefore, there are unpaired electrons in Ni^{2+} . In this complex, the d electrons from the lower energy level can be excited to the higher energy level i.e., the possibility of d-d transition is present. Hence, $[Ni(H_2O)_6]^{2+}$ is coloured. In

$[Ni(CN)_4]^{2-}$ the electrons are present as CN^- is a strong ligand. Therefore, d-d transition is not possible in $[Ni(CN)_4]^{2-}$. Hence it is colourless.

Question 21:

$[Fe(CN)_6]^{4-}$ and $[Fe(H_2O)_6]^{2+}$ are of different colours in dilute solutions. Why?

Solution 21:

The colour of a particular coordination compound depends on the magnitude of the crystal-field splitting energy, Δ

This CFSE in turn depends on the nature of the ligand. In case of

$[Fe(CN)_6]^{4-}$ and $[Fe(H_2O)_6]^{2+}$, the colour differs because there is a difference in the CFSE.

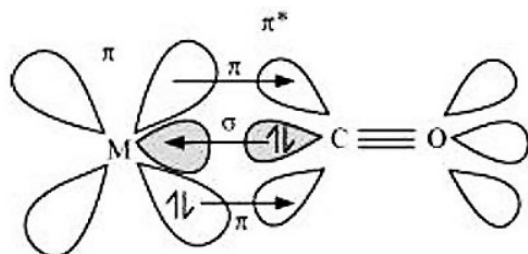
Now, CN^- is a strong field ligand having a higher CFSE value as compared to the CFSE value of water. This means that the absorption of energy for the intra $d-d$ transition also differs. Hence, the transmitted colour also differs.

Question 22:

Discuss the nature of bonding in metal carbonyls.

Solution 22:

The metal-carbon bonds in metal carbonyls have both s and p characters. $M-C\sigma$ bond is formed by the donation of lone pair of electrons on the carbonyl carbon into a vacant orbital of the metal. $M-C\pi$ bond is formed by the donation of a pair of electrons from the filled metal d orbital into the vacant anti-bonding π^* orbital of carbon monoxide. This is also known as back bonding of the carbonyl group. The metal to ligand bonding creates a synergic effect which strengthens the bond between CO and the metal. This synergic effect strengthens the bond between CO and the metal.



Synergic bonding in metal carbonyls

Question 23:

Give the oxidation state, d -orbital occupation and coordination number of the central metal ion in the following complexes:

- (i) $K_3[Co(C_2O_4)_3]$
- (ii) $cis-[Cr(en)_2Cl_2]Cl$
- (iii) $(NH_4)_2[CoF_4]$
- (iv) $[Mn(H_2O)_6]SO_4$

Solution 23:

- (i) $K_3[Co(C_2O_4)_3]$

The central metal ion is Co.

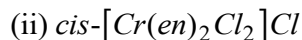
Its coordination number is 6.

The oxidation state can be given as:

$$x - 6 = -3$$

$$x = +3$$

The d orbital occupation for Co^{3+} is $t_2g^6 eg^0$



The central metal ion is Cr.

The coordination number is 6.

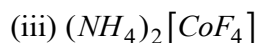
The oxidation state can be given as:

$$x + 2(0) + 2(-1) = +1$$

$$x - 2 = +1$$

$$x = +3$$

The d orbital occupation for Co^{3+} is t_2g^3



The central metal ion is Co.

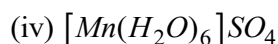
The coordination number is 4.

The oxidation state can be given as:

$$x - 4 = -2$$

$$x = +2$$

The d orbital occupation for Co^{3+} is $t_2g^5 eg^2$



The central metal ion is Mn.

The coordination number is 6.

The oxidation state can be given as:

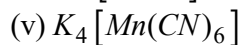
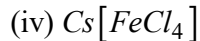
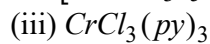
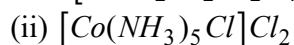
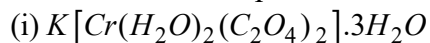
$$x + 0 = +2$$

$$x = +2$$

The d orbital occupation for Mn is $t_2g^3 eg^2$

Question 24:

Write down the IUPAC name for each of the following complexes and indicate the oxidation state, electronic configuration and coordination number. Also give stereochemistry and magnetic moment of the complex:



Solution 24:

(i) Potassium diaquadioxalatochromate (III) trihydrate.

Oxidation state of chromium = +3

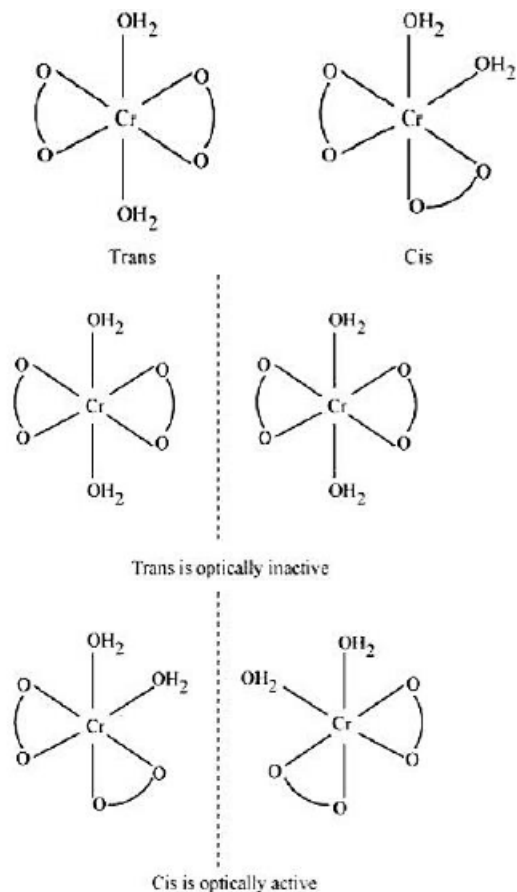
Electronic configuration: $3d^3.t^3_{2g}$

Coordination number = 6

Shape: octahedral

Stereochemistry:

Chapter 9 Coordination Compound



Both isomers are optically active. Therefore, a total of 4 isomers exist.

$$\mu = \sqrt{n(n+2)}$$

$$= \sqrt{3(3+2)}$$

Magnetic moment, $= \sqrt{15}$

$$= 3.87 \text{ BM}$$



IUPAC name: Pentaamminechloridocobalt(III) chloride

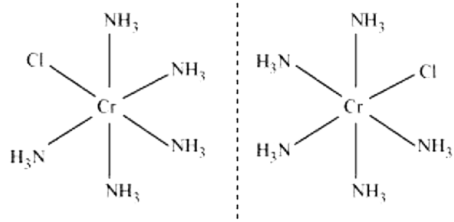
Oxidation state of Co = +3

Coordination number = 6

Shape: octahedral.

Electronic configuration: $d^6 : t_{2g}^6$.

Stereochemistry:



2 isomers

Magnetic Moment = 0

(iii) $CrCl_3(py)_3$

IUPAC name: Trichloridotripyridinechromium (III)

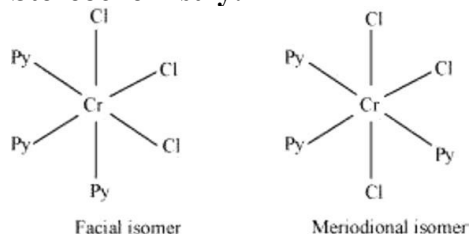
Oxidation state of chromium = +3

Electronic configuration for $d^3 : t_{2g}^3$

Coordination number = 6

Shape: octahedral.

Stereochemistry:



(iv) $Cs[FeCl_4]$

IUPAC name: Caesium tetrachloroferrate (III)

Oxidation state of Fe = +3

Electronic configuration of $d^6 = e^2_g t^3_{2g}$

Coordination number = 4

Shape: tetrahedral

Stereochemistry: optically inactive

Magnetic moment:

$$\mu = \sqrt{n(n+2)}$$

$$= \sqrt{5(5+2)}$$

$$= \sqrt{35} = 5.92 BM$$

(v) $K_4[Mn(CN)_6]$

Potassium hexacyanomanganate(II)

Oxidation state of manganese = +2

Electronic configuration: $d^5 : t^5_{2g}$

Coordination number = 6

Shape: octahedral.

Stereochemistry: optically inactive

Magnetic moment,

$$\mu = \sqrt{n(n+2)}$$

$$= \sqrt{1(1+2)}$$

$$= \sqrt{3}$$

$$= 1.732 BM$$

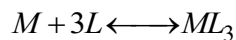
Question 25:

What is meant by stability of a coordination compound in solution? State the factors which govern stability of complexes.

Solution 25:

Chapter 9 Coordination Compound

The stability of a complex in a solution refers to the degree of association between the two species involved in a state of equilibrium. Stability can be expressed quantitatively in terms of stability constant or formation constant.



$$\text{Stability constant, } \beta = \frac{[ML_3]}{[M][L]^3}$$

For this reaction, the greater the value of the stability constant, the greater is the proportion of ML_3 in the solution. Stability can be of two types:

(a) Thermodynamic stability:

The extent to which the complex will be formed or will be transformed into another species at the point of equilibrium is determined by thermodynamic stability.

(b) Kinetic stability:

This helps in determining the speed with which the transformation will occur to attain the state of equilibrium.

Factors that affect the stability of a complex are:

(a) Charge on the central metal ion: The greater the charge on the central metal ion, the greater is the stability of the complex.

1. Basic nature of the ligand: A more basic ligand will form a more stable complex.

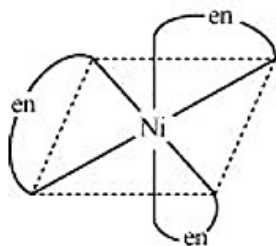
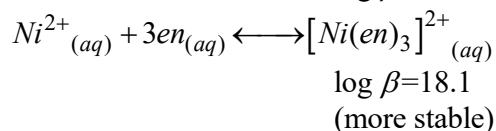
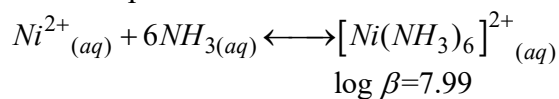
2. Presence of chelate rings: Chelation increases the stability of complexes.

Question 26:

What is meant by the *chelate* effect? Give an example.

Solution 26:

When a ligand attaches to the metal ion in a manner that forms a ring, then the metal- ligand association is found to be more stable. In other words, we can say that complexes containing chelate rings are more stable than complexes without rings. This is known as the chelate effect. For example:



Question 27:

Discuss briefly giving an example in each case the role of coordination compounds in:

- (i) biological system
- (ii) medicinal chemistry
- (iii) analytical chemistry
- (iv) extraction/metallurgy of metals

Solution 27:**(i) Role of coordination compounds in biological systems:**

We know that photosynthesis is made possible by the presence of the chlorophyll pigment. This pigment is a coordination compound of magnesium. In the human biological system, several coordination compounds play important roles. For example, the oxygen-carrier of blood, i.e., haemoglobin, is a coordination compound of iron.

Vitamin B12 cyanocobalamin the anti-pernicious anaemia factor is a coordination compound of cobalt. Among the other compounds of biological importance with coordinated metal ions are the enzymes like carboxypeptidase A and carbonic anhydrase

(ii) Role of coordination compounds in medicinal chemistry:

Certain coordination compounds of platinum (for example, *cis*-platin) are used for inhibiting the growth of tumours.

The excess of metal ions present in toxic proportions in plant and animal systems like copper and iron are removed by chelating ligands D-penicillamine and desferrioxime B via the formation of coordination compounds. EDTA is used in the treatment of lead poisoning .

(iii) Role of coordination compounds in analytical chemistry:

During salt analysis, a number of basic radicals are detected with the help of the colour changes they exhibit with different reagents. These colour changes are a result of the coordination compounds or complexes that the basic radicals form with different ligands.

E.g. EDTA, DMG, cupron etc

(iv) Role of coordination compounds in extraction or metallurgy of metals:

The process of extraction of some of the metals from their ores involves the formation of complexes. For example, in aqueous solution, gold combines with cyanide ions to form $Au(CN)_2$. From this solution, gold is later extracted by the addition of zinc metal.

Question 28:

How many ions are produced from the complex $Co(NH_3)_6Cl_2$ in solution?

- (i) 6
- (ii) 4
- (iii) 3
- (iv) 2

Solution 28:

(iii) The given complex can be written as $Co(NH_3)_6Cl_2$

Thus, $[Co(NH_3)_6]^{2+}$ along with two Cl^- ions are produced.

Question 29:

Amongst the following ions which one has the highest magnetic moment value?

- (i) $[Cr(H_2O)_6]^{3+}$
 (ii) $[Fe(H_2O)_6]^{2+}$
 (iii) $[Zn(H_2O)_6]^{2+}$

Solution 29:

(i) No. of unpaired electrons in $[Cr(H_2O)_6]^{3+} = 3$

Then,

$$\begin{aligned}\mu &= \sqrt{n(n+2)} \\ &= \sqrt{3(3+2)} \\ &= \sqrt{15} \\ &3.87BM\end{aligned}$$

(ii) No. of unpaired electrons in $[Fe(H_2O)_6]^{2+} = 4$

Then,

$$\begin{aligned}\mu &= \sqrt{4(4+2)} \\ &= \sqrt{24} \\ &4.89BM\end{aligned}$$

(iii) No. of unpaired electrons in $[Zn(H_2O)_6]^{2+} = 0$

Hence, $[Fe(H_2O)_6]^{2+}$ has the highest magnetic moment value.

Question 30:

The oxidation number of cobalt in $K[Co(Co)_4]$ is

- (i) +1
 (ii) +3
 (iii) -1
 (iv) -3

Solution 30:

We know that CO is a neutral ligand and K carries a charge of +1.

Therefore, the complex can be written as $K^+[Co(Co)_4]^-$ Therefore, the oxidation number of Co in the given complex is -1. Hence, option (iii) is correct.

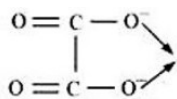
Question 31:

Amongst the following, the most stable complex is

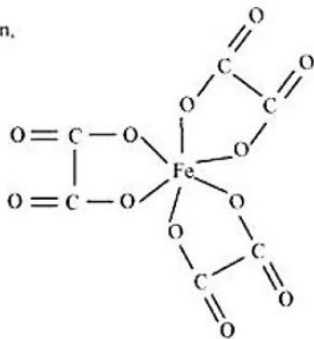
- (i) $[Fe(H_2O)_6]^{3+}$
 (ii) $[Fe(NH_3)_6]^{3+}$
 (iii) $[Fe(C_2O_4)_3]^{3-}$
 (iv) $[FeCl_6]^{3-}$

Solution 31:

We know that the stability of a complex increases by chelation. Therefore, the most stable complex is $[Fe(H_2O)_6]^{3+}$



Then,

**Question 32:**

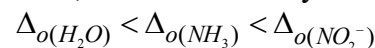
What will be the correct order for the wavelengths of absorption in the visible region for the following: $[Ni(NO_2)_6]^{4-}$, $[Ni(NO_3)_6]^{2+}$, $[Ni(H_2O)_6]^{2+}$

Solution 32:

The central metal ion in all the three complexes is the same. Therefore, absorption in the visible region depends on the ligands. The order in which the CFSE values of the ligands increases in the spectrochemical series is as follows:



Thus, the amount of crystal-field splitting observed will be in the following order:



Hence, the wavelengths of absorption in the visible region will be in the order:

