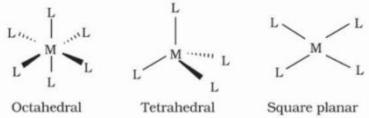


COORDINATION COMPOUNDS

IUPAC Nomenclature



Addition Compounds

Double Compound

Complex Compounds

Terminology related to Coordination Compounds

Isomerism

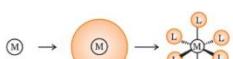
COORDINATION COMPOUNDS

Coordination entity	Wavelength of light absorbed (nm)	Colour of light absorbed	Colour of coordination entity
$[\text{CoCl}(\text{NH}_3)_5]^{2+}$	535	Yellow	Violet
$[\text{Co}(\text{NH}_3)_5(\text{H}_2\text{O})]^{3+}$	500	Blue Green	Red
$[\text{Co}(\text{NH}_3)_6]^{3+}$	475	Blue	Yellow Orange
$[\text{Co}(\text{CN})_6]^{3-}$	310	Ultraviolet	Pale Yellow
$[\text{Cu}(\text{H}_2\text{O})_4]^{2+}$	600	Red	Blue
$[\text{Ti}(\text{H}_2\text{O})_6]^{3+}$	498	Blue Green	Purple

Bonding in Coordination Compounds

Werner's Theory

Valence Bond Theory

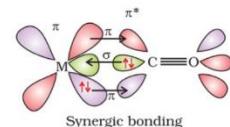


Crystal Field Theory

Octahedral Complex

Tetrahedral Complex

Bonding in Metal Carbonyl





Co-ordination Chemistry

Chemistry of D-block Elements

21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.986	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38
39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41
57 La Lanthanum 138.91	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59
89 Ac Actinium (227)	104 Rf Rutherfordium (267)	105 Db Dubnium (288)	106 Sg Seaborgium (289)	107 Bh Bohrium (270)	108 Hs Hassium (277)	109 Mt Meitnerium (278)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (282)	112 Cn Copernicium (282)

3d Series Elements

4th Period

21

30

21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.986	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38
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Mnemonics (3d Series) –

Science Ticher Very Cruel Mange Fees Copy Niha Cukkar Zindabad

4d Series Elements

39

48

39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41
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Mnemonics (4d Series) –

Yari Zra Nibhana Mot Tac Rukawat Rah Pde to Aag Cudo



5d Series Elements

57 La Lanthanum 138.91	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 190.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59
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Mnemonics (5d Series) –

La HafTa Warna Re Osama Idhar Pitayi Aur Hogi

21 Sc Scandium 44.956
39 Y Yttrium 88.906
57 La Lanthanum 138.91
89 Ac Actinium (227)

22 Ti Titanium 47.867
40 Zr Zirconium 91.224
72 Hf Hafnium 178.49
104 Rf Rutherfordium (267)

Tina Zor se Haf Rafi Hai

23 V Vanadium 50.942
41 Nb Niobium 92.908
73 Ta Tantalum 180.95
105 Db Dubnium (268)

ViNb Ta

24 Cr Chromium 51.996
42 Mo Molybdenum 95.99
74 W Tungsten 183.84
106 Sg Seaborgium (269)

25 Mn Manganese 54.938
43 Tc Technetium (98)
75 Re Rhenium 190.21
107 Bh Bohrium (270)

Mannat Tac Rekha Bhig Chuki Hai

26 Fe Iron 55.845
44 Ru Ruthenium 101.07
76 Os Osmium 190.23
108 Hs Hassium (277)

Fer Rua Osama

27 Co Cobalt 58.933
45 Rh Rhodium 102.91
77 Ir Iridium 192.22
109 Mt Meltnerium (278)

28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38
46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41
78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59
110 Ds Darmstadtium (281)	111 Rg Roentgenium (282)	112 Cn Copernicium (282)

Nahi Padhoge to Pitoge

Cu aAge aAu

Zindgi Cadbury Hogayi

3d Series Elements (Electronic Configuration)

Sc – [Ar] 4s²3d¹

Ti – [Ar] 4s²3d²

V – [Ar] 4s²3d³

***Cr** – [Ar] 4s¹3d⁵

Mn – [Ar] 4s²3d⁵

Fe – [Ar] 4s²3d⁶

Co – [Ar] 4s²3d⁷

Ni – [Ar] 4s²3d⁸

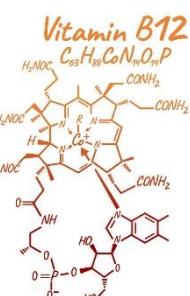
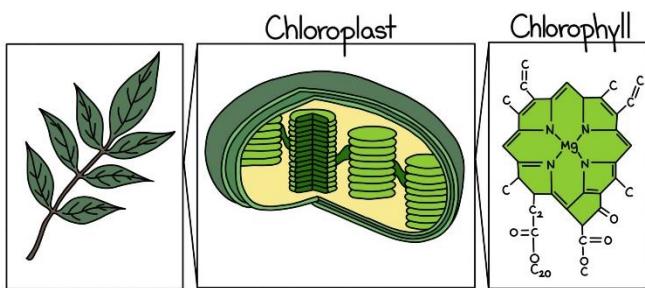
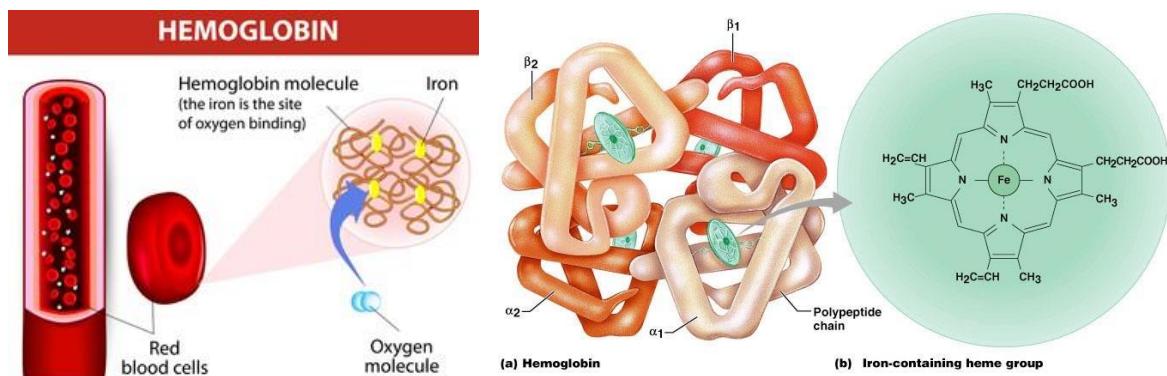
***Cu** – [Ar] 4s¹3d¹⁰

Zn – [Ar] 4s²3d¹⁰

Uses of Co-ordination Chemistry

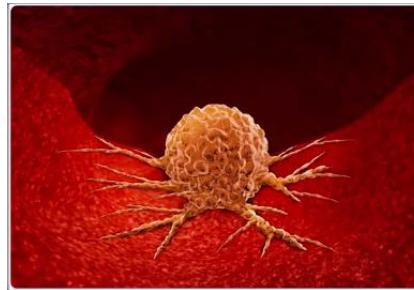
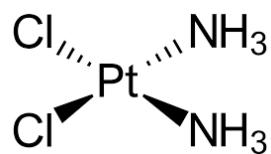
→ Biological Systems

- Haemoglobin
- Chlorophyll
- Vitamin B₁₂



→ Medicine

→ Cis Platin



→ Metallurgy

→ Extraction of metals like Gold/Silver

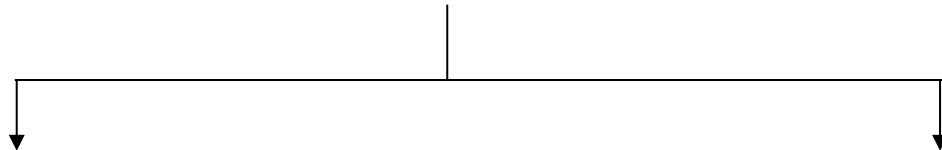
→ Catalyst

→ Wilkinson Catalyst

Co-ordination Chemistry

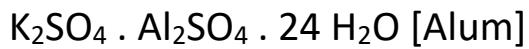
Addition Compounds : They are formed by the combination of two or more stable compounds in stoichiometric ratio. [CBSE 2019] [1M]

Addition Compounds

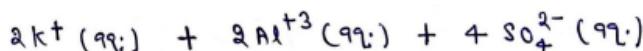


Double Salts

→ Compounds which lose their identity in solution are called double salts.



$\uparrow \uparrow \text{H}_2\text{O (Aqueous)}$

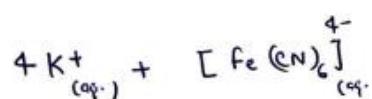


Coordination Compounds

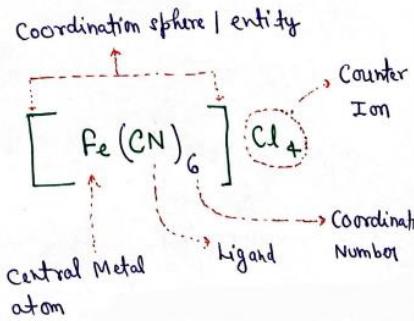
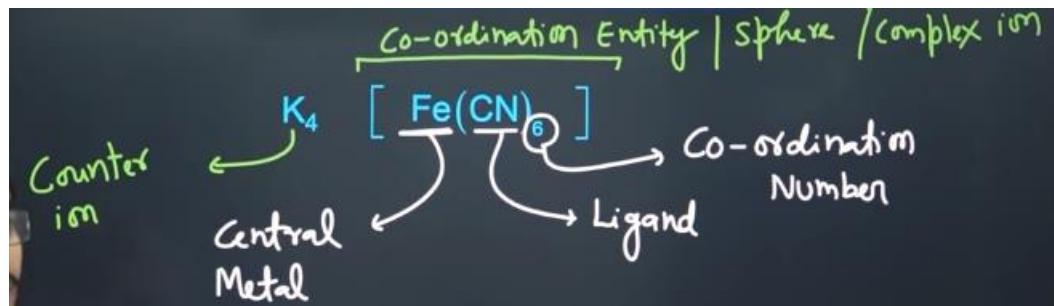
→ Compounds which does not lose their identity in solution are called Coordination compound.



$\uparrow \uparrow \text{aq.}$



Terminology related to Co-ordination Compounds :-



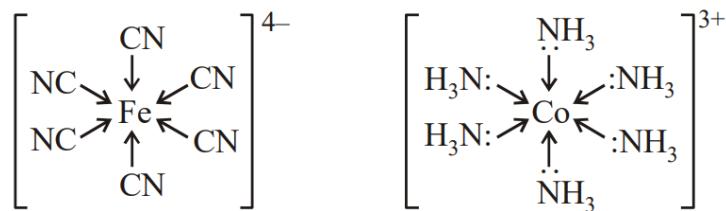
Co-ordination Entity

The Central atom/ion and the ligands attached to it are enclosed in square brackets are collectively known as Co-ordination entity or Co-ordination Sphere

Ligands

The **ligands** are the ions or molecules bound to the central atom/ion in the coordination entity.

For example: $[Fe(CN)_6]^{4-}$, $[Co(NH_3)_6]^{3+}$



The donor atoms, ions or molecules which donate a pair of electrons to the central metal atom/ion are called ligands.

Denticity

The no. of donor atoms present in a **ligand**, is called denticity of ligand.

- **Unidentate / Monodentate** : Only one donor atom [Cl^- /NH₃/H₂O etc]
- **Bidentate/didentate** : When a ligand can bind through two donor atoms

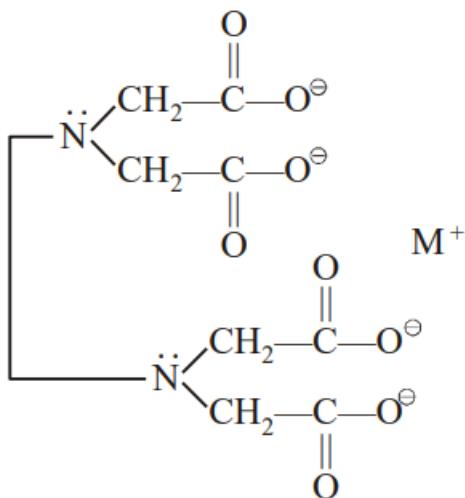
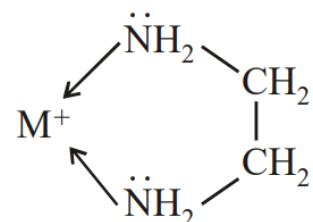
For example :- Ethane-1, 2-diamine [NH₂-CH₂-CH₂-NH₂]

Or

Ethylenediamine [en]

→ **Polydentate** : More than two donor atoms

For example :- → Ethylene diamine tetra-acetate ion



→ [EDTA]⁴⁻ : Hexadentate Ligand

→ it can bind through two nitrogen and four oxygen atoms to a central metal ion.

Monodentate Ligand

Only one donation is accepted from the ligand

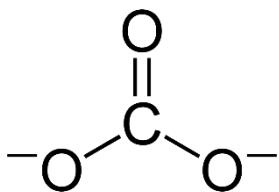
ite	ito	(Nitrite) NO_2^- - Nitrito
ide	ido	(Hydroxide) OH^- - Hydroxo/Hydroxido
ate	ato	(Nitrate) NO_3^- - Nitrato

Ligands	Name
H_2O	Aqua
CO	Carbonyl
NO	Nitrosyl
NH_3	Ammine

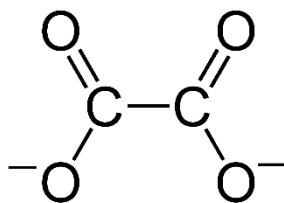
F^-	Fluorido
Cl^-	Chlorido
Br^-	Bromido
I^-	Iodido
NO^+	Nitrosonium
NH_2^-	Amido
CH_3-NH_2	Methylamine
CH_3COO^-	Acetato
OH^-	Hydroxo
H^-	Hydrido
CN^-	Cyano/Cyanido
O^{2-}	Oxo/Oxido
O_2^{2-}	Peroxido/peroxo
O_2^-	Superoxo
C_5H_5N	Pyridine
N^{3-}	Nitrido
N_3^-	Azido
$C_2O_4^{2-}$	Oxalato

Bidentate Ligand

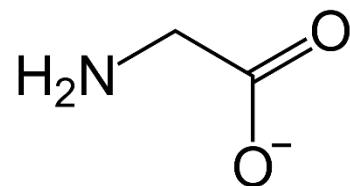
Two donations are accepted from the ligand.



Carbonato



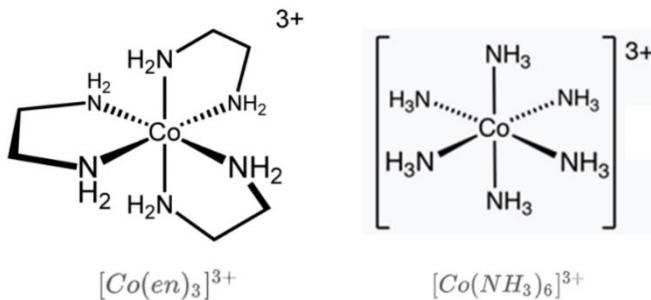
Oxalato



Glycinato

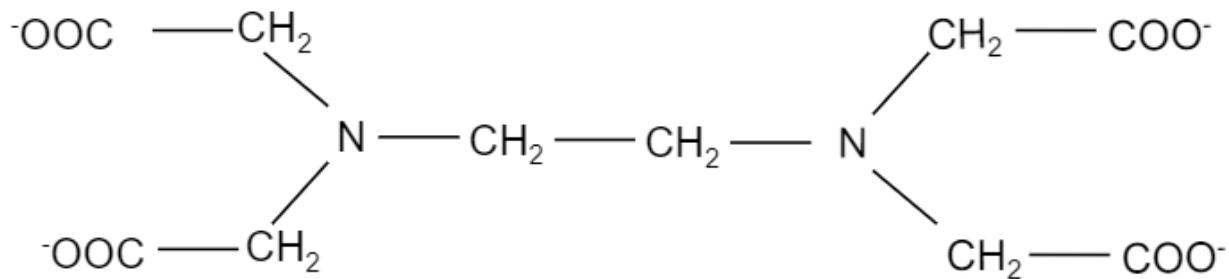
Chelation

Chelates are generally **more stable** than non-chelate complexes.



Polydentate Ligand

EDTA – Ethylene Diamine Tetra-acetate ion

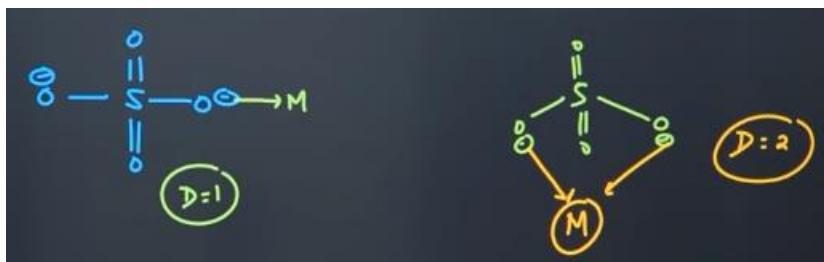


Denticity = 6 (Hexa dentate) [2 from N, 4 from O]

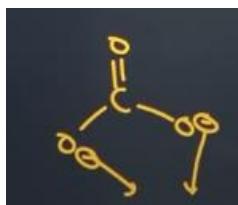
Flexidentate Ligand

A polydentate ligand with different denticity in different coordination compounds

SO₄²⁻

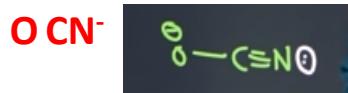
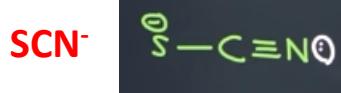
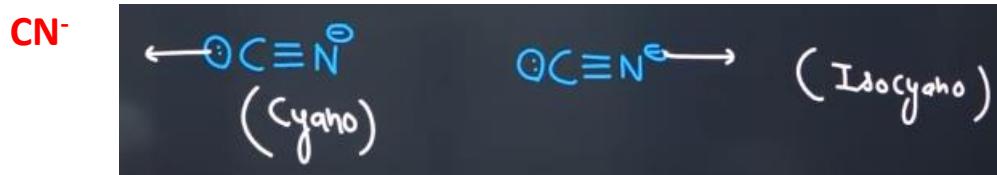
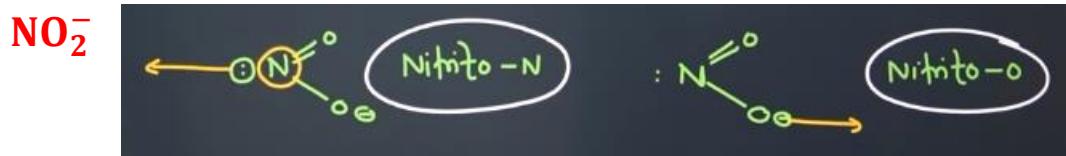


CO_3^{2-} , EDTA



Ambidentate Ligand

Ligands that have **more than one kind of donor sites**

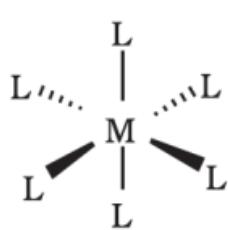


Co-ordination Number

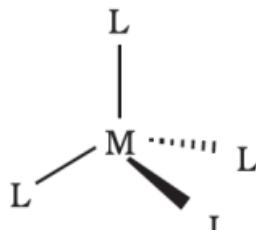
The no. of ligand donor atoms to which the metal is directly bonded.

For example: $[\text{PtCl}_6]^{2-}$: C.N. \Rightarrow 6

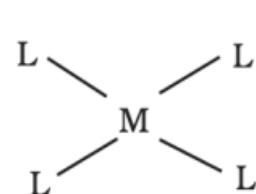
$[\text{Ni}(\text{NH}_3)_4]^{2+}$: C.N. \Rightarrow 4



Octahedral



Tetrahedral

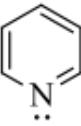
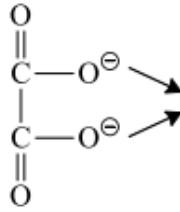
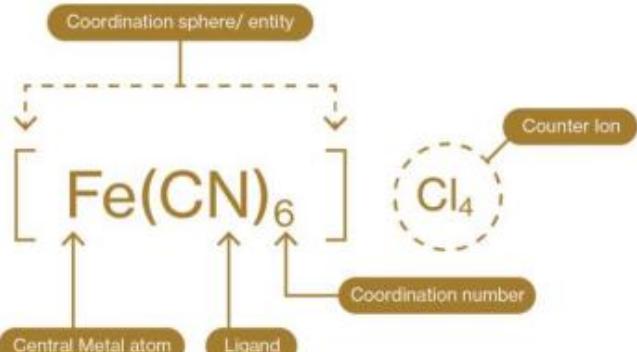


Square planar

Homoleptic and heteroleptic complexes :

- Complexes in which a metal is bound to only one kind of donor groups are known as homoleptic.
- For example : $[\text{Co}(\text{NH}_3)_6]^{3+}$
- Complexes in which a metal is bound to more than one kind of donor groups are known as heteroleptic complex.

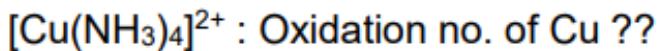
For example: $[\text{Co}(\text{NH}_3)_4\text{Cl}_2]^+$

Formula	IUPAC Name	Formula	IUPAC Name
 or $\text{C}_5\text{H}_5\text{N}$	Pyridine	NO	Nitrosyl
$\ddot{\text{N}}\text{H}_3$	Ammine	NO_2^-	Nitrito-N / Nitro
H_2O	Aqua	ONO^-	Nitrito-O
CO	Carbonyl	NH_2^-	Amido
$\text{R}-\text{NH}_2$	Alkyl amine		Oxalato [Ox^{2-}]
Cl^-	Chlorido	OH^-	Hydroxo
Br^-	Bromido		
CN^-	Cyanido/cyano		
CO_3^-	Carbonato		
SCN^-	Thiocyanato		



Oxidation Number of Central atom :

Oxidation no. of CA + sum of charge on total ligands = charge on co-ordination sphere.



$$x + 4 \text{ (charge on } \text{NH}_3) = 2$$

$$x + 4 * 0 = 2 \text{ then } x = +2$$

NOMENCLATURE OF CO-ORDINATION COMPOUNDS

Rules for writing formula of mononuclear co-ordination complexes :

- Formula of cation [simple or complex] is written first.
- Co-ordination entity is enclosed in square bracket.
- In coordination sphere, metal atom is written first, followed by ligands in alphabetical order of their names.
- In abbreviated ligands [like en/Ox] → first letter of abbreviation is considered
- When ligands are polyatomic, their formulas are enclosed in parenthesis.

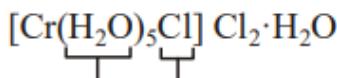
For example: (SCN), (PPh₃) etc.

- There should be no space between the ligands and the metal.
- For charged coordination entity : Charge is indicated outside the square brackets as a right superscript with the no. before the sign.

For example: [Co(CN)₆]³⁻, [Cr(H₂O)₆]³⁺ etc.

- The Charge of the cation is balanced by the charge of anion.

For example:



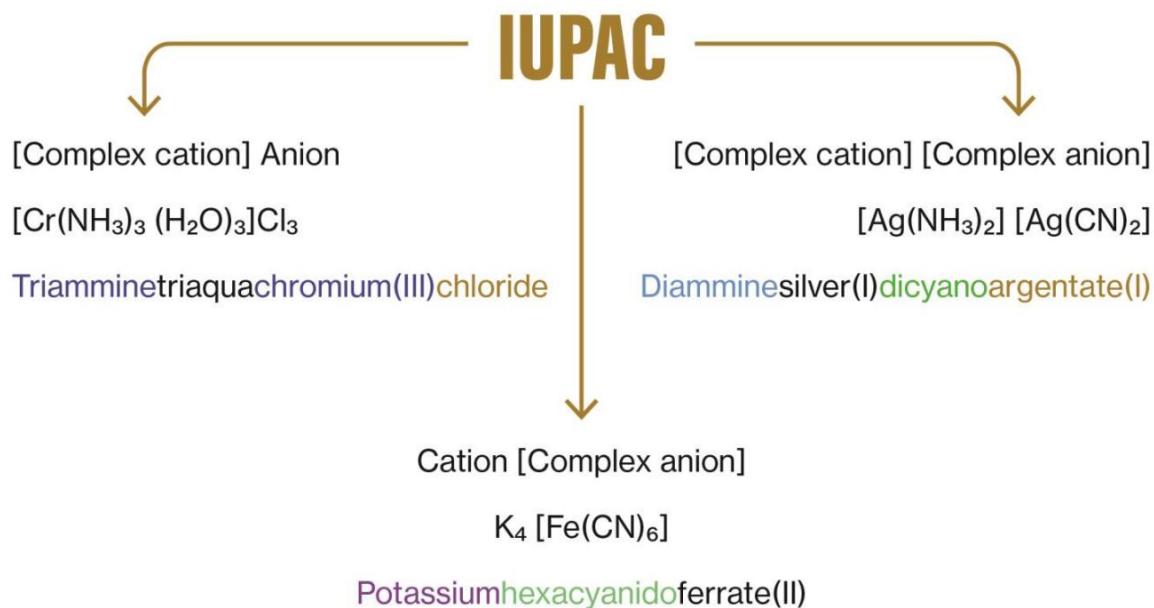
Alphabetical order:

Aqua > Chloro



Rules for naming of mononuclear co-ordination complexes :

- (a) Complex cation is named first followed by anion (if present).
- (b) The ligands are named in alphabetical order before the name of metal atom/ion.
- (c) Names of anionic ligands end in 'O' [For ex : Cyano/Chlorido]
Neutral ligands have no special ending [$\text{H}_2\text{O} \rightarrow \text{Aqua}$, $\text{NH}_3 \rightarrow \text{ammine}$]
Positive ligands end in 'ium'. [$\text{NO}^+ : \text{Nitrosonium}$]
- (d) Prefixes mono, di, tri are used to indicate the number of the individual ligands.
 - When the names of ligands include a numerical prefix, then terms bis, tris, tetrakis are used, the ligand to which they refer being placed in parenthesis.
- (e) Oxidation state of metal is indicated by roman numerical in parenthesis.
- (f) If complex ion is a cation, the metal is named same as the element.
 - If complex ion is an anion, the name of the metal ends with suffix 'ate'.
 - The neutral complex molecule is named similar to that of the complex cation.





1. $[\text{Cr}(\text{NH}_3)_3(\text{H}_2\text{O})_3]\text{Cl}_3$: triamminetriaquachromium(III)chloride

$$\text{Oxidation no. of Cr} + 3(\text{charge on NH}_3) + 3(\text{charge on H}_2\text{O}) + 3(\text{charge on chlorine}) = 0$$

- Oxidation no. of Cr + 3*0 + 3*0 + 3*(-1) = 0
 - Oxidation no. of Cr = +3

2. $[\text{Co}(\text{NH}_2-\text{CH}_2-\text{CH}_2-\text{NH}_2)_3]_2 (\text{SO}_4)_3$: Tris(ethane-1,2-diamine)cobalt(III)sulphate

- $2(x + 3^*O) + 3(-2) = 0$
 - $x = +3$

3. $[\text{Ag}(\text{NH}_3)_2]$ $[\text{Ag}(\text{CN})_2]$: Diamminesilver(I)dicyanoargentate(I)

+ve complex ion -ve complex ion

- #### 4. $\text{Ni}(\text{CO})_4$: Tetracarbonylnickel(0)

$$x + 4(0) = 0 \text{ then } x = 0$$

5. $K_4[Fe(CN)_6]$: Potassiumhexacyanidoferrate (II).

$$4(+1) + x + 6(-1) = 0 \text{ then } x = +2$$

6. $[\text{Pt}(\text{en})_2\text{Cl}_2]^{2+}$: Dichloridobis(ethane-1,2-diamine)platinum(IV)ion. [CBSE 2015] [1M]

7. $[\text{Ni}(\text{NH}_3)_6]\text{Cl}_2$: Hexaammine nickel (II) chloride. [CBSE 2015(C)] [1M]

8. $[\text{PtCl}(\text{NH}_2\text{CH}_3)(\text{NH}_3)_2]\text{Cl}$: Diammine chlorido methylamine platinum (II) chloride.

[CBSE 2011(C)]

9. $[\text{Pt}(\text{NH}_3)_4\text{Cl}_2]\text{Cl}_2$: Tetraamminedichlorido platinum (IV) chloride. [CBSE 2011(C)]

10. $[\text{Cr}(\text{NH}_3)_6]$ $[\text{Co}(\text{CN})_6]$: Hexaammine chromium(III) hexacyanocobaltate (III)

+ve complex -ve complex

[CBSE 2011(C)]

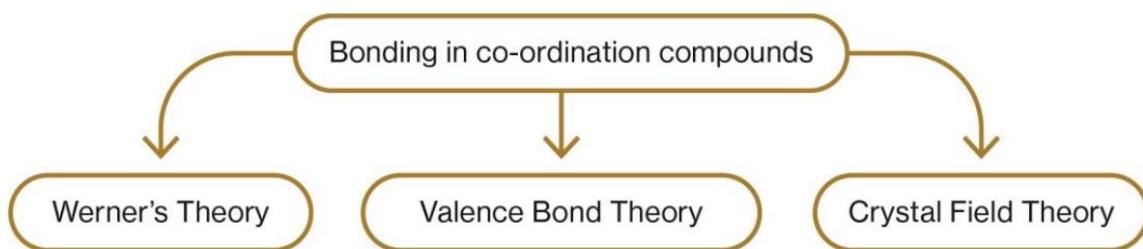
11. $[\text{Pt}(\text{NH}_3)_3(\text{NO})\text{Cl}_2]\text{Br}_2$: Triammine dichlorido nitrosyl platinum (IV) bromide. [CBSE 2011(C)]

12. $[\text{Co}(\text{CN})_2(\text{NH}_3)_4]\text{Cl}$: tetraammine dicyano cobalt (III) chloride. [CBSE 2011(C)]



13. $[\text{Cr}(\text{NH}_3)_5(\text{NCS})] \text{ [ZnCl}_4]$: Pentaammineisothiocyanatochromium(III) etrachloridezincate (II)
+ve complex -ve complex [CBSE 2011(C)]
14. $[\text{Co}(\text{NH}_3)_5\text{Cl}]\text{Cl}_2$: Pentaammine chlorido cobalt (III) chloride. [CBSE 2010(C)]
15. $[\text{Cr}(\text{NH}_3)_2\text{Cl}_2(\text{en})]\text{Cl}$: Diammine dichlorido(ethane-1,2-diamine) chromium (III) chloride. [CBSE 2015]
16. $\text{K}_3[\text{Fe}(\text{CN})_6]$: Potassiumhexacyanoferrate(III) [CBSE 2015]
17. $[\text{Co}(\text{NH}_3)_6]\text{Cl}_3$: Hexammine cobalt (III) chloride. [CBSE 2015]
18. $[\text{Co}(\text{en})_3]^{3+}$: Tris(ethane-1, 2-diamine) cobalt (III) ion. [CBSE 2018(C)]
19. $[\text{NiCl}_4]^{2-}$: Tetrachloridonickelate (II) ion. [CBSE 2015 / CBSE 2014(C)][1M]
20. $[\text{Co}(\text{NH}_3)_5(\text{NO}_2)]^{2+}$: Pentaamminenitrito-N cobalt (III) ion.
21. $[\text{Pt}(\text{NH}_3)_2\text{Cl}_2]$: Diammine dichloridoplatinum (II)
 - Co-ordination no. = 4
 - Oxidation state = +2
22. $\left[\text{Co} \left(\begin{array}{c} \text{COO}^- \\ | \\ \text{COO}^- \end{array} \right)_3 \right]^{3-}$: trioxalato cobaltate (III) ion. [CBSE 2014] [3M]
23. $[\text{Cr}(\text{CO})_6]$: Hexacarbonylchromium (0) [CBSE 2014] [3M]
24. $[\text{PtCl}_3(\text{C}_2\text{H}_4)]$: Trichloridoethene platinum (IV) [CBSE 2014] [3M]
25. $[\text{CoBr}_2(\text{en})_2]^+$: Dibromidobis (ethane-1, 2-diamine) cobalt (III) ion. [CBSE 2013]
26. $\text{K}_3[\text{Fe}(\text{C}_2\text{O}_4)_3]$: Potassiumtrioxalatoferrate (III) ion. [CBSE 2013(C)]
27. $[\text{Pt}(\text{NH}_3)_6]\text{Cl}_4$: Hexaamine platinum (IV) chloride. [CBSE 2013(C)]
28. $[\text{Cr}(\text{C}_2\text{O}_4)_3]^{3-}$: Trioxalatochromate (III) ion.
29. $[\text{Co}(\text{en})_2\text{Cl}_2]^+$: Dichloridobis (ethane-1, 2-diamine) cobalt (III) ion.
30. Hexaammine cobalt (III) sulphate : $[\text{Co}(\text{NH}_3)_6]_2(\text{SO}_4)_3$ [CBSE 2019] [2M]
31. Potassiumtrioxalatochromate (III) : $\text{K}_3[\text{Cr}(\text{C}_2\text{O}_4)_3]$ [CBSE 2019] [2M]
32. Potassium trioxalato aluminate (III) : $\text{K}_3 [\text{Al}(\text{C}_2\text{O}_4)_3]$ [CBSE 2017] [2M]

33. Dichloridobis (ethane-1, 2-diamine) cobalt (III) ion : $[\text{CoCl}_2(\text{en})_2]^+$ [CBSE 2017] [2M]
34. Pentaamminenitrito-O-cobalt (III) ion : $[\text{Co}(\text{NH}_3)_5(\text{ONO})]^{2+}$ [CBSE 2015] [1M]
35. Sodiumdicyanidoaurate(I) : $\text{Na}[\text{Au}(\text{CN})_2]$ [CBSE 2017] [2M]
36. Tetraammine chloridonitrito-N-platinum (IV) sulphate : $[\text{Pt}(\text{NH}_3)_4\text{Cl}(\text{NO}_2)]\text{SO}_4$ [CBSE 2017] [2M]
37. Mercury tetrathiocyanatocobaltate (III) : $\text{Hg}[\text{Co}(\text{SCN})_4]$
38. Potassium trioxalato aluminate (III) : $\text{K}_3[\text{Al}(\text{C}_2\text{O}_4)_3]$
39. Potassium tetrahydroxozincate (II) : $\text{K}_2[\text{Zn}(\text{OH})_4]$



WERNER'S THEORY

Werner's Theory : Werner was the first to formulate his idea about the structures of coordination compounds.

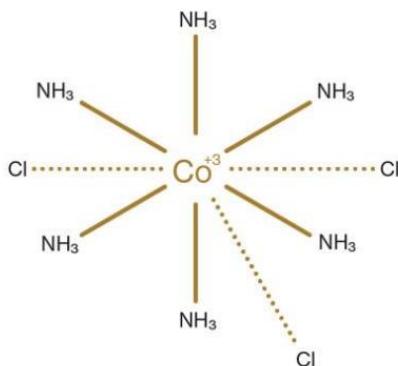
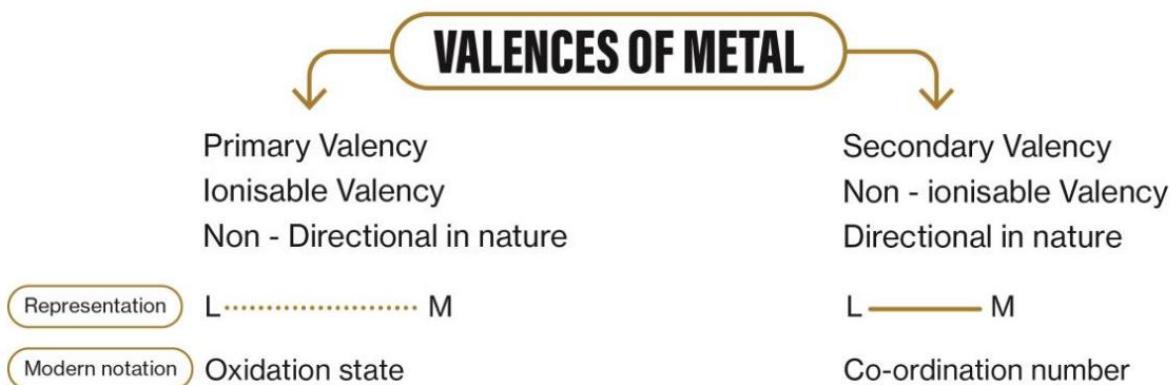
The main postulates are :

1. In coordination compounds metals show two types of valency → Primary and Secondary
2. The primary Valences are normally ionisable and are satisfied by negative ions.
3. The secondary valences are non-ionisable. These are satisfied by neutral molecules or negative ions.

4. The ions/Groups bound by secondary valency to metal have spatial arrangements corresponding to different coordination numbers.

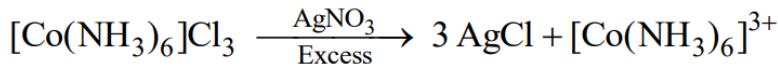
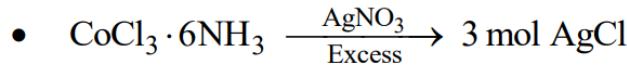
NOTE : In modern formulation :

- Primary Valency corresponds to Oxidation state of metal
- Secondary Valency corresponds to Coordination no. of central metal
- Spatial arrangement are called coordination polyhedron



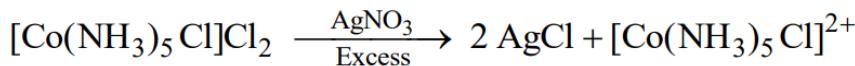
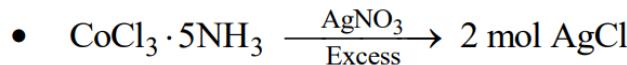


Experiments: (1) In a series of compounds of cobalt (III) chloride with ammonia, it was found that some of chloride ions could be precipitated as AgCl on adding excess AgNO₃ solution but some remained in solution.



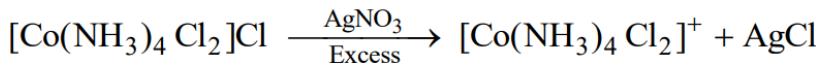
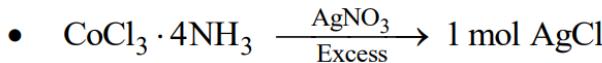
Secondary valency is satisfied by → 6NH₃ [Coordination no. = 6]

Primary valency is satisfied by → 3Cl⁻ [Co in (III) oxidation state]



Secondary valency is satisfied by → 5NH₃ and 1Cl⁻ [Coordination no. = 6]

Primary valency is satisfied by → 3Cl⁻ [Co in (III) oxidation state]



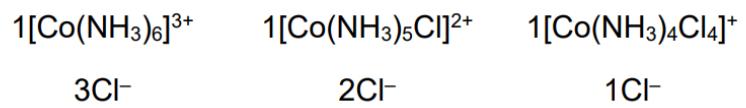
Secondary valency is satisfied by → 4NH₃ and 2Cl⁻ [Coordination no. = 6]

Primary valency is satisfied by → 3Cl⁻ [Co in (III) oxidation state]

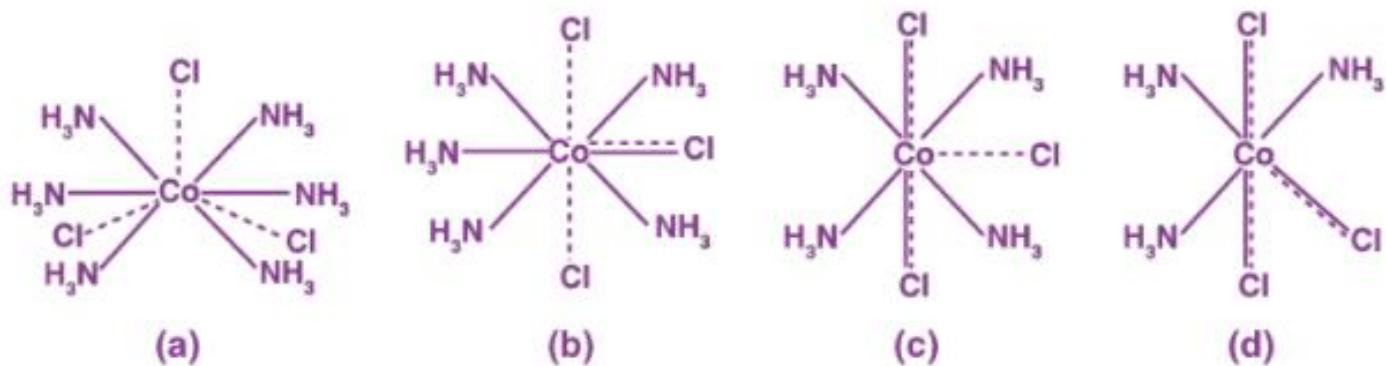
(2) As we know conductivity of a solution depends on no. of ions present in solution.

Experimental order of conductivity: CoCl₃·6NH₃ > CoCl₃·5NH₃ > CoCl₃·4NH₃

No. of ions in their solution [per mole of electrolyte] : 4 3 2

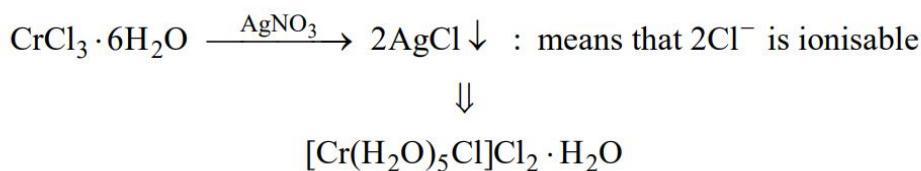


- When a coordination compound CrCl₃·6H₂O is mixed with AgNO₃, 2 moles of AgCl are precipitated per mole of compound.



Compounds		Colour	Old Name	No. of charges on complex ion	No. of Ions		
Old Formulae	New Formulae				Cation	Anion	Total
$\text{CoCl}_3 \cdot 6\text{NH}_3$	$[\text{Co}(\text{NH}_3)_6]\text{Cl}_3$	Yellow	Luteo complex	+3	1	3	4
$\text{CoCl}_3 \cdot 5\text{NH}_3$	$[\text{Co}(\text{NH}_3)_5\text{Cl}]\text{Cl}_2$	Purple	Purpureo complex	+2	1	2	3
$\text{CoCl}_3 \cdot 4\text{NH}_3$	Trans- $[\text{Co}(\text{NH}_3)_4\text{Cl}_2]\text{Cl}$	Green	Praseo complex	+1	1	1	2
$\text{CoCl}_3 \cdot 4\text{NH}_3$	Cis- $[\text{Co}(\text{NH}_3)_4\text{Cl}_2]\text{Cl}$	Violet	Violeo complex	+1	1	1	2
$\text{CoCl}_3 \cdot 3\text{NH}_3$	$[\text{Co}(\text{NH}_3)_3\text{Cl}_3]$	Blue green	—	—	—	—	—

(i) Write structural formula:

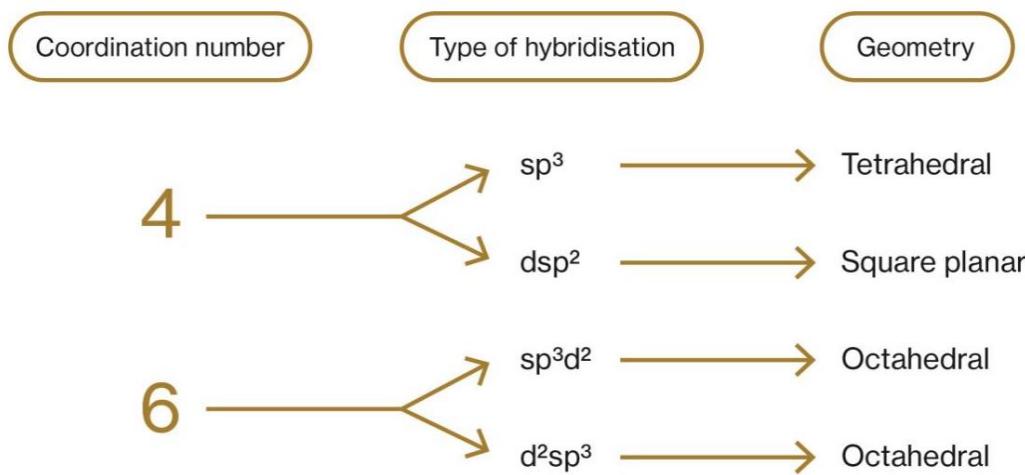


[Delhi 2014/2016 CBSE 29109] [1M]

(ii) IUPAC name of complex : Pentaquaquachloridochromium(III)chloride. [Delhi 2014] [1M]

VALENCE BOND THEORY

- According to this theory, the metal ion or atom under the influence of ligand can use its $(n - 1)d$, ns , np / ns , np , nd orbitals for hybridization to give a set of equivalent orbitals of definite geometry.
- These hybridized orbitals are allowed to overlap with ligand orbitals that can denote electron pairs for bonding.



- It is possible to predict the geometry of a complex from the knowledge of its magnetic behaviour on the basis of VBT.
- Magnetic moment of a complex on no. of unpaired electrons.

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

n = no. of unpaired electron.

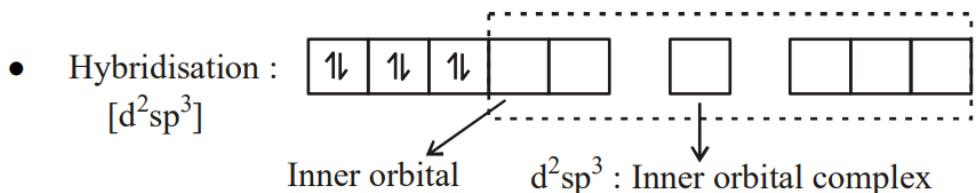
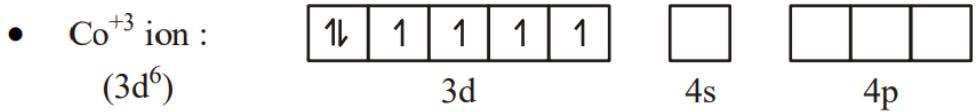
Inner orbital complex	d^2sp^3	Low spin complex	Spin paired complex.
Outer orbital complex	sp^3d^2	High spin complex	Spin free complex.

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

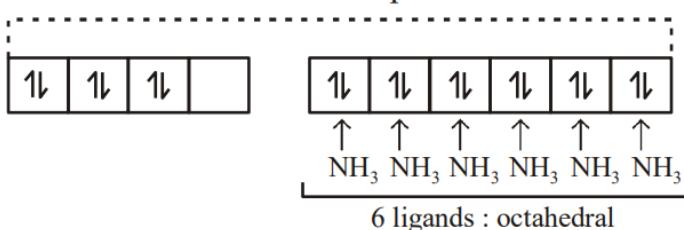
n = no. of unpaired electron.

Example: (i) $[\text{Co}(\text{NH}_3)_6]^{3+}$: Diamagnetic in nature.

[CBSE 2010] [2M]



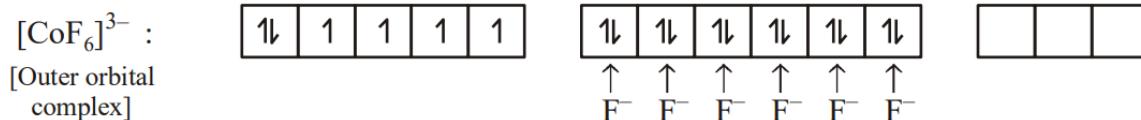
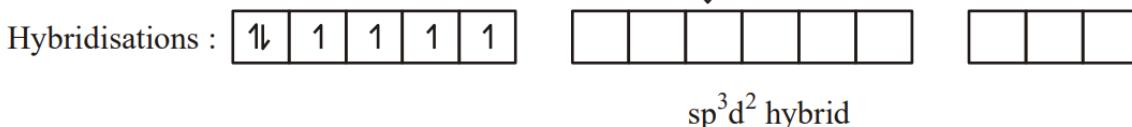
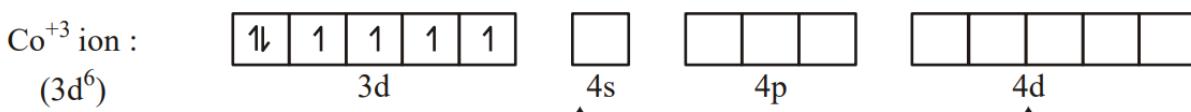
Diamagnetic
Electrons are paired



(ii) $[\text{CoF}_6]^{3-}$: Paramagnetic octahedral complex

[CBSE 2018, 2014(C), 2010]

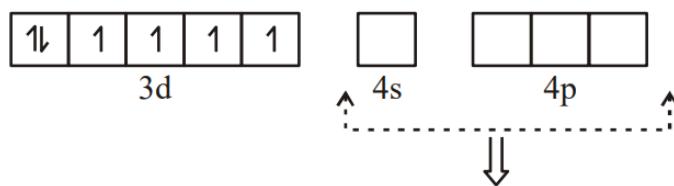
Presence of unpaired electrons.



(iii) $[\text{NiCl}_4]^{2-}$: Paramagnetic in nature.

[CBSE 2017]

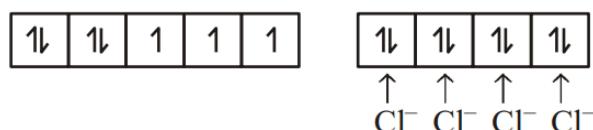
Ni^{2+} ion :
 $[\text{3d}^8]$



Hybridisations :



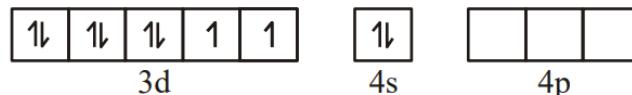
$[\text{NiCl}_4]^{2-}$:



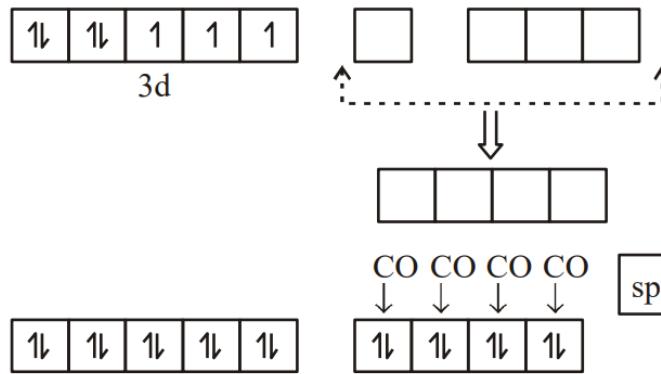
(iv) $\text{Ni}(\text{CO})_4$: Diamagnetic in nature.

[Delhi 2012]

$\text{Ni} (0)$:
 $(\text{3d}^8 \text{4s}^2)$



Hybridisations :

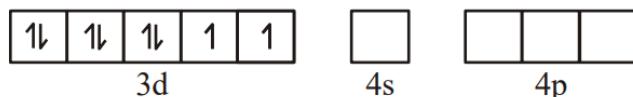


$\text{Ni}(\text{Cl})_4$:

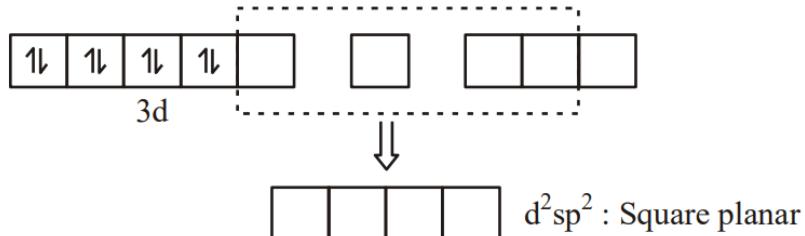


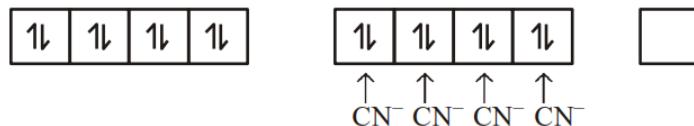
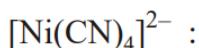
(v) $[\text{Ni}(\text{CN})_4]^{2-}$: Square planar complex : Diamagnetic. [Delhi 2010, CBSE 2019, 2011]

Ni^{+2} ion :
 (3d^8)

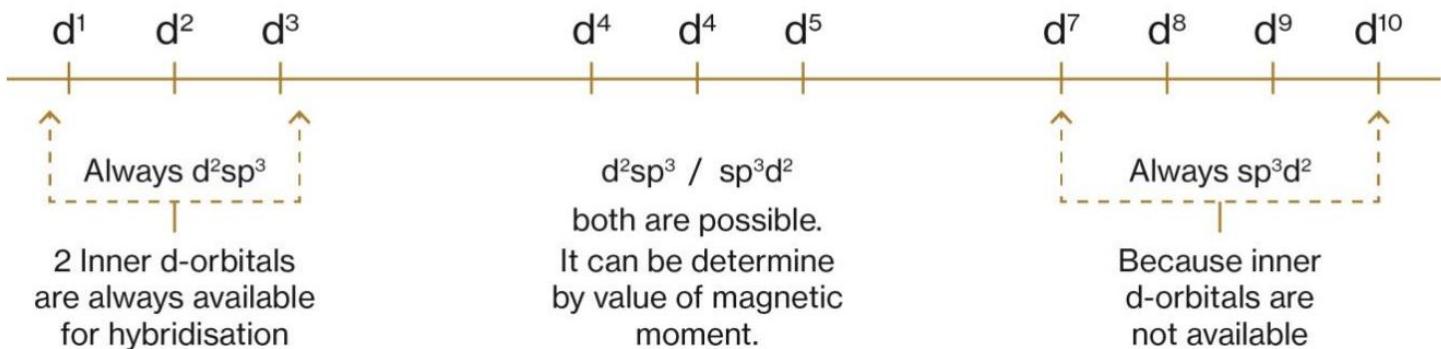


Hybridisation :





D LINE FOR HYDRIDISATION (OCTAHEDRAL)



- $[\text{Mn}(\text{CN})_6]^{3-}$: Magnetic moment of 2 electrons : d^2sp^3 : paramagnetic. [CBSE 2014]
 $[\text{MnCl}_6]^{3-}$: Magnetic moment of 3 electrons : sp^3d^2
- $[\text{Fe}(\text{CN})_6]^{3-}$: $\mu = \sqrt{n(n+2)} = \sqrt{1(1+2)}$: 1 unpaired electron : d^2sp^3
 $[\text{FeF}_6]^{3-}$: $\mu = \sqrt{5(5+2)}$: 5 unpaired electron : High spin complex $[\text{sp}^3\text{d}^2]$
- $[\text{Co}(\text{C}_2\text{H}_4)_3]^{3-}$: Diamagnetic : d^2sp^3 : inner orbital complex. [CBSE 2017] [1M]
 $[\text{CoF}_6]^{3-}$: Paramagnetic with four unpaired electron : sp^3d^2 .

Limitation of VBT

1. It involves no. of assumptions.
2. It does not explain colour of coordination compounds.
3. It does not give explanation of kinetic and thermodynamic stabilities of complex.
4. It does not distinguish between weak and strong ligands.

CRYSTAL FIELD THEORY

- CFT is an electrostatic model which considers the metal – ligand bond to be ionic, arising purely from electrostatic interactions between the metal ion and ligands.
- Ligands are treated as point charges in case of anions (Cl^- , Br^- , OH^-) or dipoles in case of neutral molecules (H_2O / NH_3 etc)

CRYSTAL FIELD THEORY

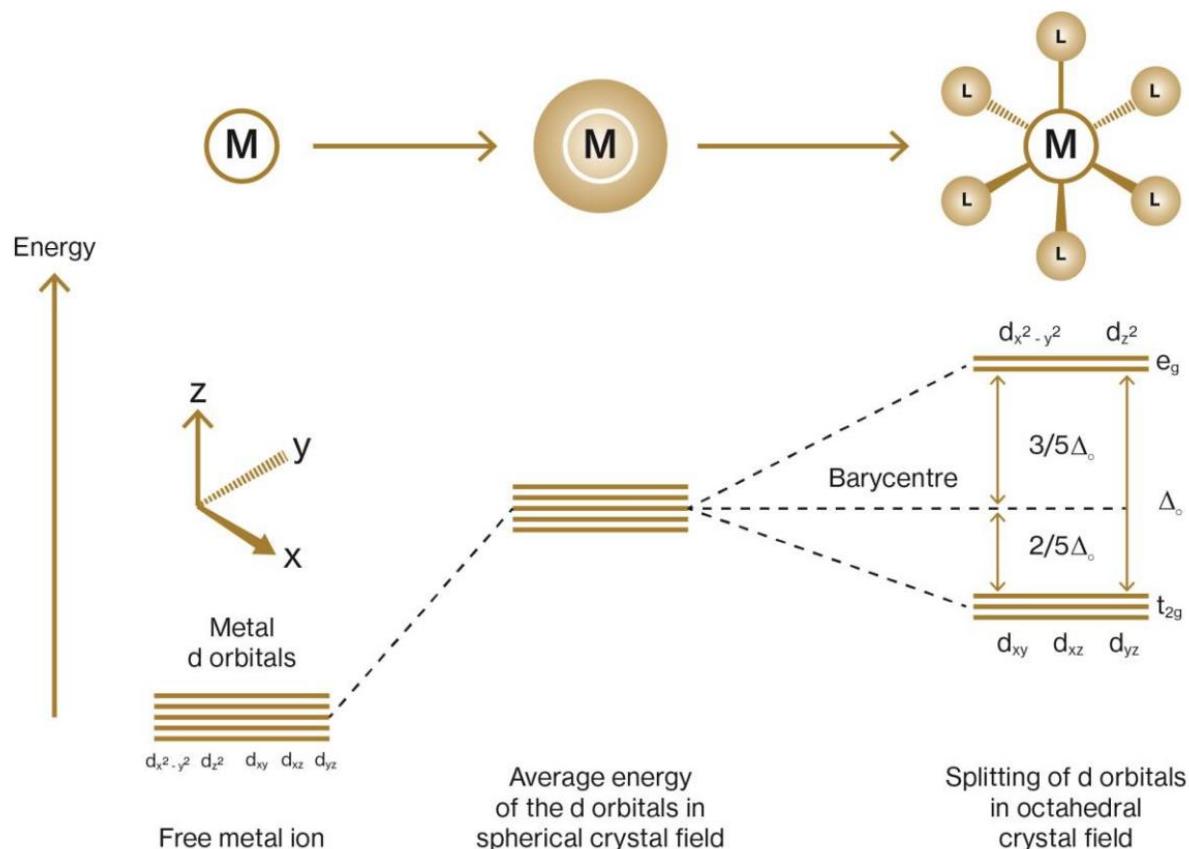
ELECTROSTATIC MODEL WHICH CONSIDER THE METAL - LIGAND BOND TO BE IONIC.



Crystal Field Splitting in Octahedral Complexes

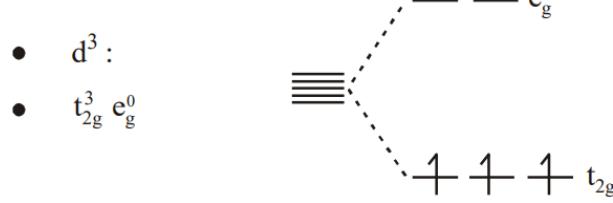
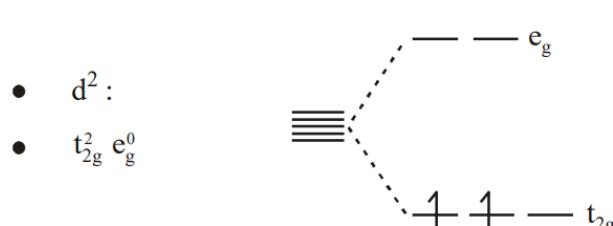
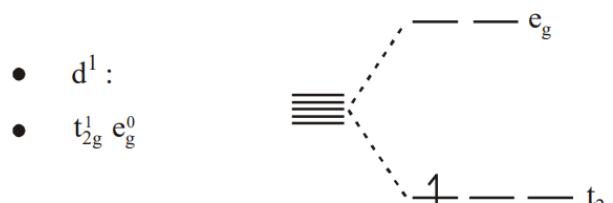
- Under the influence of 6 ligands degeneracy of d orbitals has been removed due to ligand-metal electron repulsions in octahedral complex.
- Removal of degeneracy gives three orbitals [d_{xy} , d_{yz} , d_{zx}] of lower energy (t_{2g}) and two orbitals of higher energy [d_{z^2} , $d_{x^2-y^2} = e_g$ set].
- $d_{x^2-y^2}$ and d_{z^2} orbitals point towards the axes along the direction of the ligand, will experience more repulsion and will raised in energy.
- d_{xy} , d_{yz} , d_{zx} orbitals are directed between axes, will be lowered in energy relative to average energy (in the spherical crystal field).
- Splitting of degenerate levels due to the presence of ligands in a definite geometry is called **Crystal field splitting** and the energy separation is denoted by Δ_o [Crystal field splitting energy].

[CBSE 2011(C)] [2M]

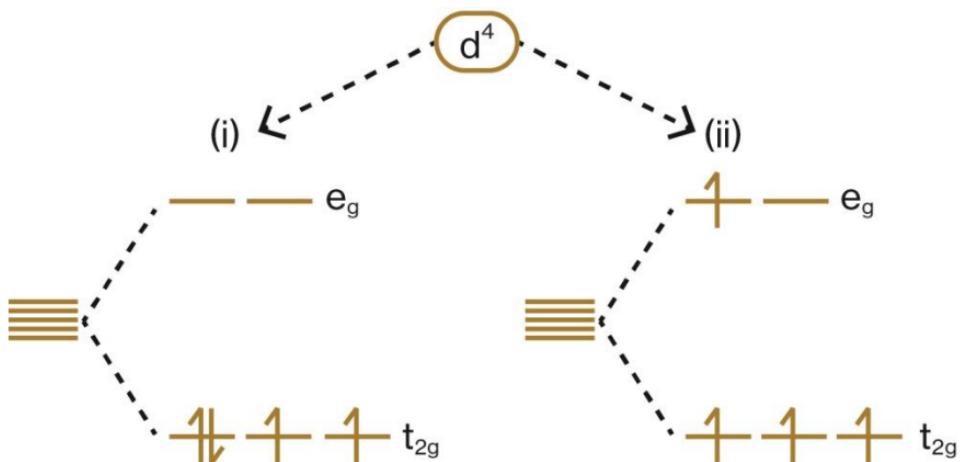


d orbital splitting in an octahedral crystal field

- The extent of splitting depends upon the field produced by ligand and charge on metal ion.



[CBSE 2013] [3M]



(i) If $\Delta_0 > P$ [P = pairing energy]

Now 4th electron enters into t_{2g} orbital and configuration = $t_{2g}^4 e_g^0$

(ii) If $\Delta_0 < P$

Here, 4th electron enters in to one of e_g orbitals giving the configuration $t_{2g}^3 e_g^1$.

- Ligands for which $\Delta_0 > P$ are known as strong field ligand. [SFL]

- Ligands for which $\Delta_0 < P$ are known as weak field ligand. [WFL]

SPECTROCHEMICAL SERIES

If ligands are arranged in a series in the order of increasing field strength, then that series is called spectrochemical series.

SPECTROCHEMICAL SERIES

SERIES OF LIGANDS IN THE ORDER OF INCREASING FIELD STRENGTH.

Halogen donors < Oxygen donors < Nitrogen donors < Carbon donors

$I^- < Br^- < SCN^- < Cl^- < S^{2-} < OH^- < C_2O_4^{2-} < NCS^- < EDTA^{4-} < NH_3 < en < CN^- < CO$

3D SERIES

Metal (+2)	$(I^- \rightarrow en)$	WFL
Metal (+3)	$(I^- \rightarrow H_2O)$	WFL
Metal (+4)	All ligands are SFL	

BUT

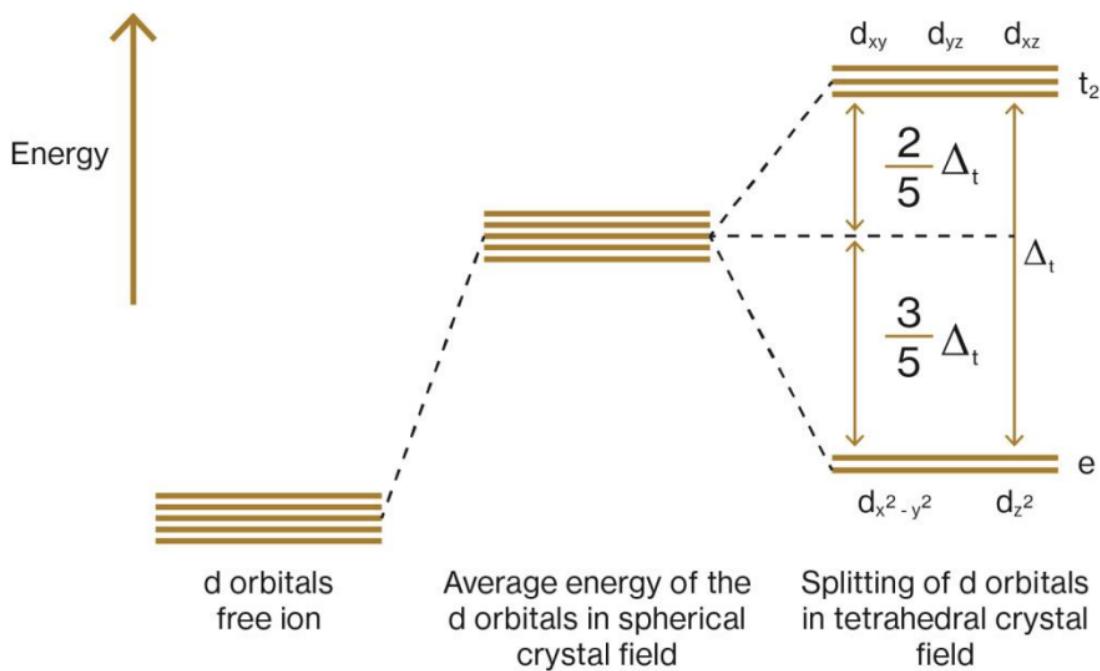
Co^{+3}	$OH^- \rightarrow CO$	SFL
	$I^- \rightarrow F^-$	WFL

4D / 5D SERIES

Metal (+2)	All ligands are SFL
Metal (+3)	
Metal (+4)	

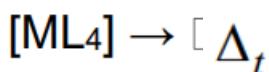
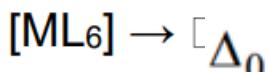
Crystal Field Splitting in tetrahedral Complexes

- In tetrahedral coordination entity formation the d orbital splitting is inverted and is smaller as compared to the octahedral field splitting.

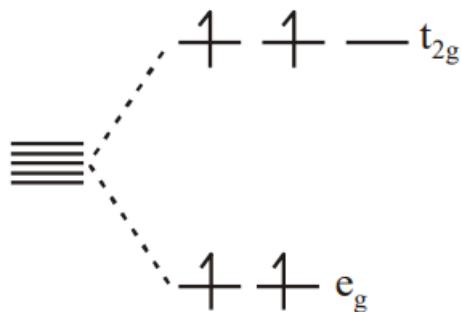




- For same metal and ligand : $\Delta_t = \frac{4}{9} \Delta_0$

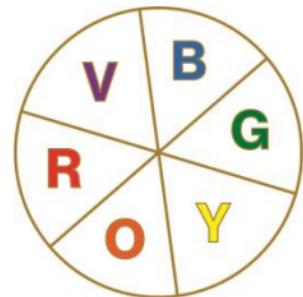


- $[\text{ML}_4]$: d^4 configuration
 - $e_g^2 t_{2g}^2$



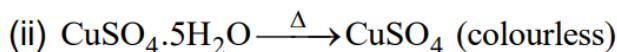
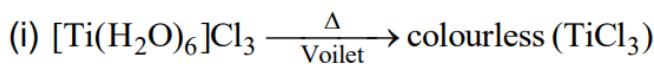
COLOUR IN COORDINATION COMPOUNDS

- When light of certain frequency falls on the complex, it absorbs light from visible range for transition of electrons from lower d -energy level to higher d energy level.
This transition is called $d-d$ transition of electron.
 - Colour of the compound is the complementary colour of absorbed light. For example if green is absorbed by the complex, it appears red.



- | | | |
|--------------------------------------------------------------------------|---------------------------|-----------------------|
| $\bullet \quad \text{Ti}(\text{H}_2\text{O})_6]^{3+}$: Violet in colour | $\text{---} - \text{e}_g$ | $+ - \text{e}_g$ |
| \downarrow | | Transition |
| $\text{d}^1 : t_{2g}^1 \ e_g^0$ | $- + - t_{2g}$ | $\text{---} - t_{2g}$ |
| Transition : $t_{2g}^1 \ e_g^0$ to $t_{2g}^0 \ e_g^1$ | Ground State | Excited State |

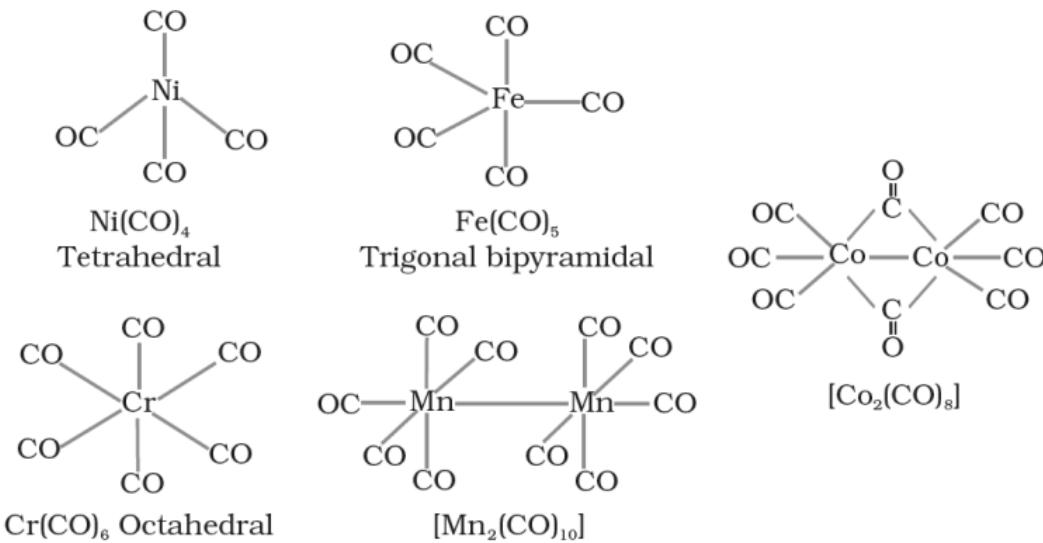
- In absence of ligand crystal field splitting does not occur and hence the substance is colourless



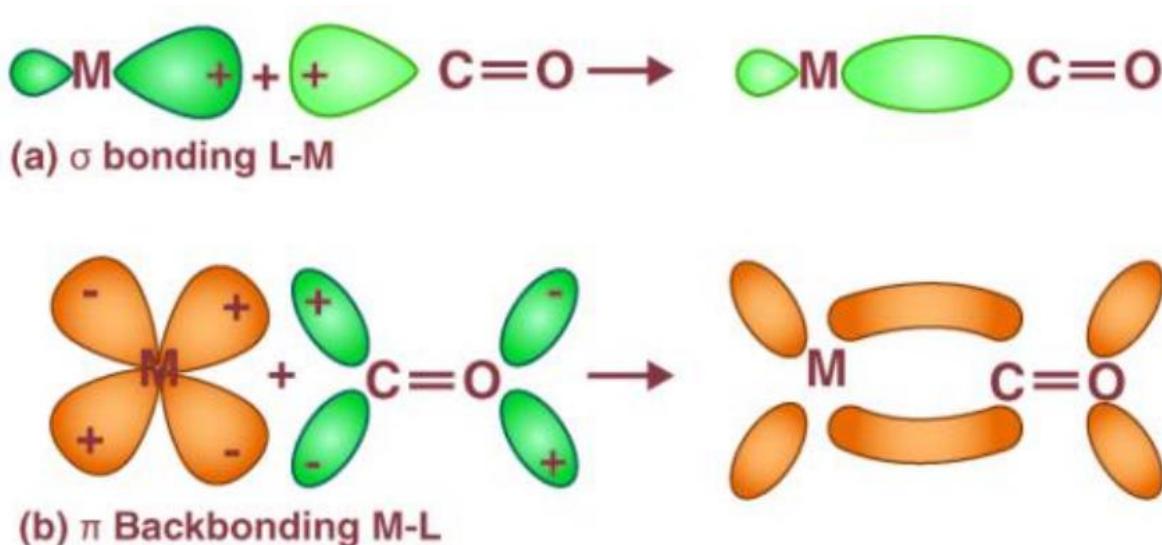
Limitations of CFT: From the assumptions that the ligands are point charges, it follows that anionic ligands should exert the greatest splitting effect. But it is not true because anionic ligands are found at the low end of spectrochemical series.

Bonding in Metal Carbonyls

- Compounds which have atleast one metal-carbon bond are called organometallic compounds.
- The metal carbon bond in metal carbonyls possesses both σ and π character.



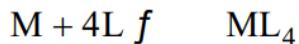
- The M—C σ bond is formed by the donation of lone pair of electrons from the carbonyl carbon to a vacant orbital of metal.
- The M—C π bond is formed by the donation of a pair of electron from a filled d-orbital of metal into vacant π^* orbital of CO.



- The metal to ligand bonding creates a **Synergic Effect** which strengthens the bond between CO and the metal.

Stability of Co-ordination Compounds

- The stability of complex in solution refers to the degree of association between the two species involved in the state of equilibrium.
- Equilibrium constant for the association expresses the stability



Value of equilibrium constant $\uparrow \Rightarrow [ML_4] \uparrow$

- Stepwise stability constant: The equilibrium constant of each step of a complex reaction is called stepwise stability constant. (k_1, k_2, \dots) [CBSE 2011(C)] [2M]
- Overall stability constant: The equilibrium constant for net reaction (β_4)

(i) $M + L \rightleftharpoons ML$	$k_1 = [ML]/[M][L]$
(ii) $ML + L \rightleftharpoons ML_2$	$k_2 = [ML_2]/[ML][L]$
(iii) $ML_2 + L \rightleftharpoons ML_3$	$k_3 = [ML_3]/[ML_2][L]$
(iv) $ML_3 + L \rightleftharpoons ML_4$	$k_4 = [ML_4]/[ML_3][L]$

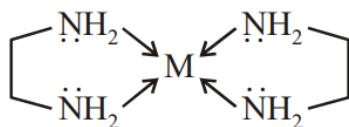


- Then $\rightarrow \beta_4 = k_1 \cdot k_2 \cdot k_3 \cdot k_4$

IMPORTANT PREVIOUS YEAR QUESTIONS

- (i) What is meant by chelate effect? [CBSE 2015] [1M]

- When a didentate | polydentate ligand containing donor atoms positioned in such a way that, they coordinate with the central metal ion forming a **five or six membered ring**. The effect is called chelate effect.
- As a result of chelate effect, the stability of the complex increases.

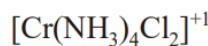
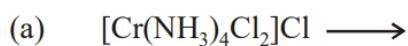


- (ii) Stability of complex : $[\text{COF}_6]^{3-} < [\text{Co(en)}_3]^{3+}$ [CBSE 2019] [1M]

- (iii) CO is stronger complexing agent than NH_3 , why? [CBSE 2012] [1M]

- There exist a back bonding in CO complexes in which CO accepts electron density from the filled σ orbitals of metal atom into their π orbital. So, there are σ as well as π interaction with metal in case of CO. But NH_3 makes only σ bond with metal. Therefore CO is a stronger complexing agent than NH_3 .

- (iv) Write the state of hybridization the shape and the magnetic behavior of following complex entities. [CBSE 2011] [3M]



d^3
No pairing happens
 \downarrow

Paramagnetic in nature due to unpaired electrons

$\text{Cr}^{+3}:$

1	1	1			
3d ³					
			4s	4p	

$[\text{Cr}(\text{NH}_3)_2\text{Cl}_2]^+:$

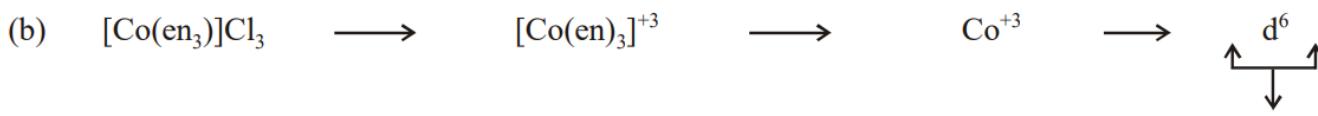
1	1	1	
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1l	1l	1l	1l	1l	1l
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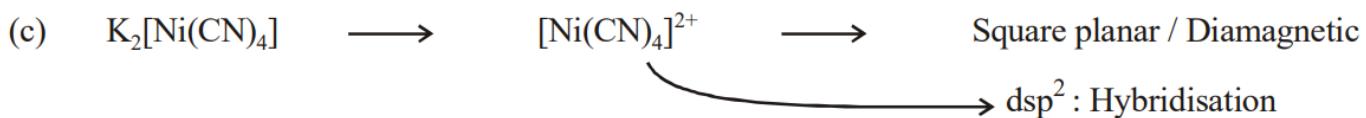
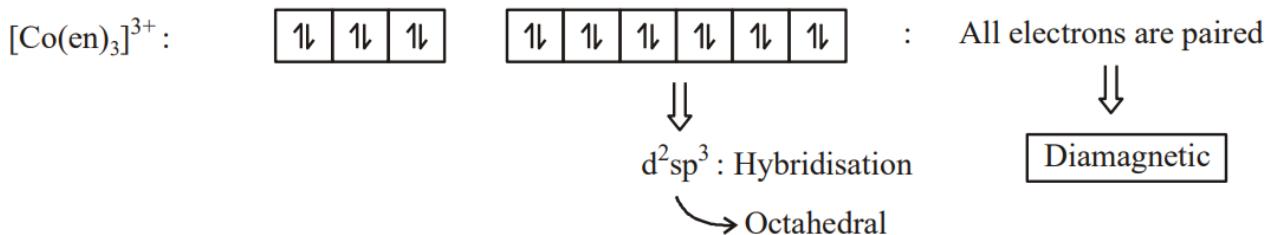
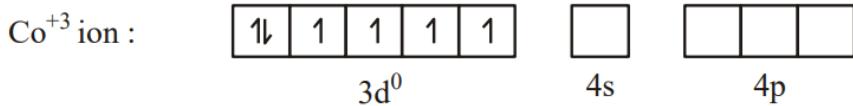
\Downarrow

$d^2\text{sp}^3$: Hybridisation

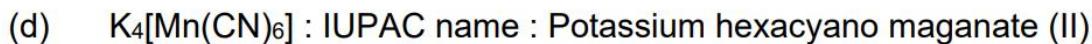
\curvearrowright Octahedral



Pairing happens due to presence of SFL (en)



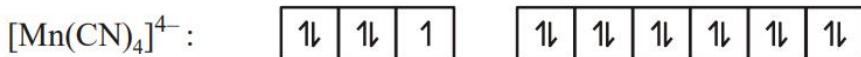
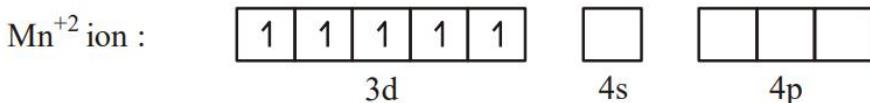
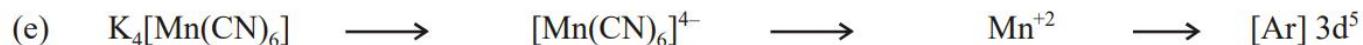
[Delhi 2011, CBSE 2012] [1M]



$$4(+1) + x + 6(-1) = 0$$

[Delhi 2011, CBSE 2010(C)] [3M]

Then $x = +2$



\Downarrow

d^2sp^3 : Octahedral : One unpaired electron

\downarrow

Paramagnetic



This Chapter Ends here !! But not your work

Go to Practice Questions, Solve Dpps attend MCQs and revise
the notes after some 2nd 4th and 7th day

To get 95+ you have to keep on revising what you studied.

[Remember Consistency and HardWork Gives Great Result]

NOTES MADE BY



MRIDUL BHAIYA



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