FREE EDITION · NOTES + 3 SAMPLE MCQS

CUET · CHEMISTRY · CLASS XII · CODE 306

Coordination Compounds

CUET unit: Coordination Compounds

By **UniDrill** · NCERT-grounded study material

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📌 Snapshot

- Establishes Werner's primary/secondary valence framework that underpins all modern coordination chemistry — primary valence is ionisable, secondary valence is the coordination number and is fixed for a metal (NCERT §5.1, p. 119-120).
- Develops the vocabulary CUET routinely tests: coordination entity, ligand (uni/di/poly/ambidentate, chelate), coordination number, coordination sphere/polyhedron, oxidation number, homoleptic vs heteroleptic (NCERT §5.2, p. 121-122).
- Builds IUPAC nomenclature rules for mononuclear complexes — cation-first, ligands alphabetical, anion ligand "-o" ending, "-ate" suffix for anionic complex, Roman-numeral oxidation state (NCERT §5.3, p. 122-124).
- Classifies isomerism (stereo: geometrical + optical; structural: linkage, coordination, ionisation, solvate) and bonding theories (VBT hybridisation sp^3/dsp^2/d^2sp^3/sp^3d^2, CFT octahedral t_{2g}/e_g splitting Δ_o, tetrahedral splitting Δ = 4/9 Δ_o, spectrochemical series, CFSE, colour from d-d transition) (NCERT §5.4-5.5, p. 125-134).
- Closes with biological/industrial importance — chlorophyll (Mg), haemoglobin (Fe), vitamin B_{12} (Co), cisplatin, EDTA chelation therapy, Wilkinson catalyst (NCERT §5.7, p. 136-137).

📖 Detailed Notes

2.1 Core concepts

- Werner studied $CoCl_3 \cdot xNH_3$ series: 1 mol $[Co(NH_3)_6]Cl_3$ gave 3 mol AgCl (1:3 electrolyte), 1 mol $[CoCl(NH_3)_5]Cl_2$ gave 2 mol AgCl (1:2), 1 mol $[CoCl_2(NH_3)_4]Cl$ gave 1 mol AgCl (1:1) — explaining the data needed primary (ionisable) and secondary (non-ionisable, fixed = coordination number) valences (NCERT §5.1, p. 118-119).
- Werner's four postulates: metals show primary + secondary linkages; primary valences are ionisable and satisfied by negative ions; secondary valences are non-ionisable, equal coordination number, satisfied by neutral molecules or negative ions; secondary-linkage groups have characteristic spatial arrangement = coordination polyhedron (NCERT §5.1, p. 119).

- Double salts (carnallite $KCl·MgCl_2·6H_2O$, Mohr's salt, potash alum) dissociate completely in water, whereas complex ions like $[Fe(CN)_6]^{4-}$ do not dissociate into Fe^{2+} and CN^- — this distinguishes a complex from a double salt (NCERT §5.1, p. 120).
- Ligands classified by donor atoms: unidentate (Cl^-, H_2O, NH_3), didentate (en = ethane-1,2-diamine; ox = $C_2O_4^{2-}$), polydentate ($N(CH_2CH_2NH_2)_3$), hexadentate ($EDTA^{4-}$ binds via 2 N + 4 O); ambidentate ligands (NO_2^-, SCN^-) have two different donor atoms; chelate complexes (di/polydentate using $\geqslant 2$ donors on the same metal) are more stable than unidentate analogues (NCERT §5.2, p. 121).
- Coordination number = number of σ-bonded ligand donor atoms; π-bonds are NOT counted. E.g. $[PtCl_6]^{2-}$ CN = 6; $[Fe(C_2O_4)_3]^{3-}$ CN = 6 (since ox is didentate) (NCERT §5.2, p. 121-122).
- Common polyhedra are octahedral (CN 6), tetrahedral and square planar (CN 4); oxidation number written as Roman numeral, e.g. Cu(I) in $[Cu(CN)_4]^{3-}$; homoleptic = one kind of donor ($[Co(NH_3)_6]^{3+}$); heteroleptic = more than one ($[Co(NH_3)_4Cl_2]^+$) (NCERT §5.2, p. 122).
- IUPAC naming: cation first; ligands alphabetical before metal; anionic ligand end "-o" (chlorido, cyanido, oxalato); neutral H_2O = aqua, NH_3 = ammine, CO = carbonyl, NO = nitrosyl; "bis/tris/tetrakis" with polyatomic ligands; Roman-numeral oxidation state in parentheses; metal in anionic complex ends in "-ate" (e.g. ferrate, cobaltate) (NCERT §5.3, p. 123-124).
- Worked examples: $[Cr(NH_3)_3(H_2O)_3]Cl_3$ = triamminetriaquachromium(III) chloride; $[Co(en)_3]_2(SO_4)_3$ = tris(ethane-1,2-diamine)cobalt(III) sulphate; $[Ag(NH_3)_2][Ag(CN)_2]$ = diamminesilver(I) dicyanidoargentate(I) (NCERT §5.3.2, p. 124).
- Isomerism — stereoisomerism: geometrical (cis-trans in square planar $[MX_2L_2]$, octahedral $[MX_2L_4]$ and $[MX_2(L\text{-}L)_2]$; fac/mer in $[Ma_3b_3]$ octahedral); optical isomerism (non-superimposable mirror images = enantiomers, d and l; common in octahedral with didentate ligands like $[Co(en)_3]^{3+}$ and cis-$[PtCl_2(en)_2]^{2+}$ but NOT in trans-$[PtCl_2(en)_2]^{2+}$) (NCERT §5.4.1-5.4.2, p. 125-127).
- Geometrical isomerism is impossible in tetrahedral complexes because the relative positions of the four unidentate ligands are identical with respect to each other (NCERT Example 5.4, p. 126).
- Structural isomerism — linkage (ambidentate ligand; $[Co(NH_3)_5(NO_2)]Cl_2$ red –ONO vs yellow $–NO_2$); coordination (ligand exchange between cation/anion complex, e.g. $[Co(NH_3)_6][Cr(CN)_6]$ vs $[Cr(NH_3)_6][Co(CN)_6]$); ionisation (counter ion swaps with ligand, e.g. $[Co(NH_3)_5(SO_4)]Br$ vs $[Co(NH_3)_5Br]SO_4$); solvate/hydrate ($[Cr(H_2O)_6]Cl_3$ violet vs $[Cr(H_2O)_5Cl]Cl_2·H_2O$ grey-green) (NCERT §5.4.3-5.4.6, p. 127-128).
- Valence Bond Theory: metal uses (n–1)d, ns, np or ns, np, nd orbitals to give hybrids — CN 4 sp^3 tetrahedral or dsp^2 square planar; CN 5 sp^3d trigonal bipyramidal; CN 6 d^2sp^3 (inner orbital / low spin) or sp^3d^2 (outer orbital / high spin) octahedral (NCERT §5.5.1 Table 5.2, p. 128).

- VBT worked examples: $[Co(NH_3)_6]^{3+}$ — Co^{3+} d^6, d^2sp^3, diamagnetic, inner orbital low-spin; $[CoF_6]^{3-}$ — sp^3d^2 outer orbital, paramagnetic with 4 unpaired e^- high-spin; $[NiCl_4]^{2-}$ — Ni^{2+} d^8, sp^3 tetrahedral, paramagnetic (2 unpaired); $[Ni(CO)_4]$ — Ni(0), sp^3 tetrahedral, diamagnetic; $[Ni(CN)_4]^{2-}$ — Ni^{2+} d^8, dsp^2 square planar, diamagnetic (NCERT §5.5.1, p. 129-130).
- Limitations of VBT: assumption-heavy; no quantitative magnetic interpretation; doesn't explain colour, thermodynamic/kinetic stability; cannot predict tetrahedral vs square planar; doesn't distinguish weak vs strong ligands (NCERT §5.5.3, p. 131).
- Crystal Field Theory: electrostatic model, ligands = point charges/dipoles, five degenerate d orbitals split in a non-spherical ligand field. Octahedral field: d_{x²–y²} and d_{z²} (e_g, axial) rise by $(3/5)\Delta_o$; d_{xy}, d_{yz}, d_{xz} (t_{2g}) fall by $(2/5)\Delta_o$. The energy gap is Δ_o (NCERT §5.5.4(a), p. 131-132).
- Spectrochemical series (increasing field strength): $I^- < Br^- < SCN^- < Cl^- < S^{2-} < F^- < OH^- < C_2O_4^{2-} < H_2O < NCS^- < EDTA^{4-} < NH_3 < en < CN^- < CO$ (NCERT §5.5.4, p. 132).
- For d^4: if $\Delta_o < P$ (pairing energy) → weak field, high-spin $t_{2g}^3e_g^1$; if $\Delta_o > P$ → strong field, low-spin $t_{2g}^4e_g^0$. Strong field ligands form low-spin complexes; d^4-d^7 are more stable in strong field than weak field (NCERT §5.5.4(a), p. 132).
- Tetrahedral field: splitting is inverted (e set lower, t_2 higher) and $\Delta_t = (4/9)\Delta_o$ — too small to force pairing, so low-spin tetrahedral complexes are rarely observed; "g" subscript dropped (no centre of symmetry) (NCERT §5.5.4(b), p. 133).
- Colour from d-d transition: e.g. $[Ti(H_2O)_6]^{3+}$ is d^1; absorbs blue-green light at 498 nm ($t_{2g}^1e_g^0 \rightarrow t_{2g}^0e_g^1$) and appears violet (complementary). Without ligand field there is no splitting → no colour: anhydrous $CuSO_4$ is white, $CuSO_4{\cdot}5H_2O$ is blue (NCERT §5.5.5, p. 133-134).
- Limitations of CFT: anionic ligands ought to split most strongly (point-charge logic) but in fact sit at the low end of the spectrochemical series; covalent ligand-metal character is ignored — addressed by LFT/MOT (NCERT §5.5.6, p. 135).
- Metal carbonyls: $Ni(CO)_4$ tetrahedral, $Fe(CO)_5$ trigonal bipyramidal, $Cr(CO)_6$ octahedral; $Mn_2(CO)_{10}$ two square-pyramidal units joined by Mn–Mn; $Co_2(CO)_8$ has Co–Co bond bridged by 2 CO. M–C bond has $\sigma + \pi$ character — σ from CO lone pair into vacant metal orbital, π from filled metal d into vacant π^* of CO = synergic bonding (NCERT §5.6, p. 135-136).
- Importance — qualitative/quantitative analysis (EDTA, DMG, cupron); hardness of water by Na_2EDTA titration; extraction of gold/silver via $[Au(CN)_2]^-$ and Zn displacement; purification of Ni via $[Ni(CO)_4]$; biology: chlorophyll (Mg), haemoglobin (Fe), vitamin B_{12} cyanocobalamine (Co), carboxypeptidase A, carbonic anhydrase; Wilkinson catalyst $[(Ph_3P)_3RhCl]$ for alkene hydrogenation; electroplating from $[Ag(CN)_2]^-$ and $[Au(CN)_2]^-$; photographic fixing as $[Ag(S_2O_3)_2]^{3-}$; chelate therapy — D-penicillamine and desferrioxime B for excess Cu/Fe, EDTA for lead poisoning, cis-platin for tumours (NCERT §5.7, p. 136-137).

2.2 Definitions to memorise

Term	Definition	Page
Coordination entity	Central metal atom/ion bonded to a fixed number of ions/ molecules, e.g. $[CoCl_3(NH_3)_3]$	121
Central atom/ion	Atom/ion in the entity to which a fixed number of ions/groups are bound in a definite geometry; acts as Lewis acid	121
Ligand	Ion/molecule bound to the central atom in a coordination entity	121
Unidentate	Ligand bound through a single donor atom (Cl^-, H_2O, NH_3)	121
Didentate	Ligand binding through two donor atoms (en, $C_2O_4^{2-}$)	121
Polydentate	Ligand with several donor atoms (e.g. $N(CH_2CH_2NH_2)_3$); $EDTA^{4-}$ is hexadentate	121
Ambidentate	Ligand with two different donor atoms, only one of which ligates at a time (NO_2^-, SCN^-)	121
Chelate ligand	Di/polydentate ligand simultaneously using $\geqslant 2$ donor atoms on the same metal; chelate complexes are more stable than unidentate analogues	121
Denticity	Number of ligating groups of a chelate ligand	121
Coordination number	Number of σ-bonded ligand donor atoms attached to the central metal (π bonds not counted)	121-122
Coordination sphere	Central atom + attached ligands enclosed in square brackets; ions outside are counter ions	122
Coordination polyhedron	Spatial arrangement of ligand donor atoms about the central metal — octahedral, tetrahedral, square planar	122
Oxidation number	Charge the central atom would carry if ligands were removed with their shared electron pairs; Roman numeral in parentheses	122
Homoleptic	Metal bound to only one kind of donor (e.g. $[Co(NH_3)_6]^{3+}$)	122
Heteroleptic	Metal bound to more than one kind of donor (e.g. $[Co(NH_3)_4Cl_2]^+$)	122
Enantiomers	Non-superimposable mirror image optical isomers; d (right-rotating) and l (left-rotating)	126
Crystal field splitting Δ_o	Energy separation between e_e and t_2g sets in octahedral field; e_e rises by $(3/5)\,\Delta_o$, t_2g falls by $(2/5)\,\Delta_o$	131-132
Spectrochemical series	Experimental ordering of ligands by field strength: $I^- < Br^- < SCN^- < Cl^- < S^{2-} < F^- < OH^- < C_2O_4^{2-} < H_2O < NCS^- < EDTA^{4-} < NH_3 < en < CN^- < CO$	132
Pairing energy P	Energy required to pair two electrons in a single orbital	132

Term	Definition	Page
Synergic bonding	σ donation from ligand to metal + π back-donation from metal d to ligand π^* (in metal carbonyls)	136

2.3 Diagrams / processes to remember

- Fig. 5.1 — Shapes of coordination polyhedra (octahedral, square planar, tetrahedral) with M and unidentate L (p. 122).
- Fig. 5.2 / 5.3 / 5.4 — cis-trans isomers of $[Pt(NH_3)_2Cl_2]$, $[Co(NH_3)_4Cl_2]^+$, $[CoCl_2(en)_2]$ (p. 125-126).
- Fig. 5.5 — fac and mer isomers of $[Co(NH_3)_3(NO_2)_3]$ (p. 126).
- Fig. 5.6 / 5.7 — Optical d/l isomers of $[Co(en)_3]^{3+}$ and cis-$[PtCl_2(en)_2]^{2+}$ (p. 126).
- Fig. 5.8 — Octahedral d-orbital splitting diagram with t_2g lower (by 2/5 Δ_o) and e_e upper (by 3/5 Δ_o) (p. 132).
- Fig. 5.9 — Tetrahedral d-orbital splitting (inverted, e lower, t_2 upper, Δ? = 4/9 Δ_o) (p. 133).
- Fig. 5.10 — d^1 electron transition $t_2g^1e_e^0 \rightarrow t_2g^0e_e^1$ explaining violet colour of $[Ti(H_2O)_6]^{3+}$ (p. 134).
- Fig. 5.11 — Colour change as en progressively replaces H_2O in $[Ni(H_2O)_6]^{2+} \rightarrow [Ni(en)_3]^{2+}$ (green → pale blue → blue/purple → violet) (p. 134).
- Fig. 5.13 — Structures of $Ni(CO)_4$, $Fe(CO)_5$, $Cr(CO)_6$, $Mn_2(CO)_{10}$, $[Co_2(CO)_8]$ (p. 136).
- Fig. 5.14 — Synergic bonding (σ ligand → metal + π metal → ligand π^*) in carbonyls (p. 136).

2.4 Common confusions / NTA trap points

- Coordination number counts σ-bonded donor atoms only, NOT the number of ligand molecules: en is didentate, so $[Co(en)_3]^{3+}$ has CN = 6, not 3 (NCERT p. 121-122).
- In tetrahedral complexes geometrical isomerism is NOT possible because all four ligands are equivalent in spatial relation; tetrahedral complexes also rarely show low-spin behaviour because Δ? = (4/9) Δ_o is below pairing energy (p. 126, 133).
- Inner orbital / low spin / spin paired (d^2sp^3, uses (n−1)d) vs outer orbital / high spin / spin free (sp^3d^2, uses nd): same magnetic moment label can confuse — strong-field ligand (CN^-, CO) gives inner orbital, weak-field (F^-, Cl^-, H_2O) gives outer orbital (p. 129-131).
- NCERT spectrochemical series places anionic ligands (I^-, Br^-, Cl^-, F^-) at the WEAK end and neutral CO, CN^- at the strong end — this contradicts CFT's pure point-charge logic and is one of CFT's stated limitations (p. 132, 135).
- Ionisation isomers and coordination isomers are both "structural" but differ in mechanism — ionisation swaps a ligand with the counter ion of the SAME complex ($[Co(NH_3)_5(SO_4)]Br$ vs $[Co(NH_3)_5Br]SO_4$), whereas coordination isomers exchange

ligands between TWO complex ions of different metals ($[Co(NH_3)_6][Cr(CN)_6]$ vs $[Cr(NH_3)_6][Co(CN)_6]$) (p. 127-128).

- "g" subscript (t_{2g}, e_g) is used only for centrosymmetric geometries — octahedral and square planar — NOT for tetrahedral, whose levels are written as e and t_2 (p. 133).
- **EAN rule** — Effective Atomic Number = Z − ox. state + 2×CN; classical EAN noble-gas configurations rationalise CN choices but EAN is not always obeyed (NCERT mentions historical relevance).
- **Chelate effect** — Polydentate (en, EDTA) complexes are more stable than monodentate analogues of equal donor count due to entropy gain on ring formation (p. 138).

2.5 Quick reference table — coordination chemistry essentials

#	Item	Formula / Detail	Page
1	Primary valence	Oxidation state of metal	120
2	Secondary valence	Coordination number	120
3	Δ ? vs Δ_o	Δ ? = (4/9) Δ_o	133
4	Spin-only μ	$\mu = \sqrt{[n(n+2)]}$ BM	130
5	Octahedral splitting	t_{2g} ($-0.4\Delta_o$) / e_g ($+0.6\Delta_o$)	133
6	Tetrahedral splitting	e (lower) / t_2 (upper)	133
7	Strong-field ligands	CO, CN^-, NO_2^-	132
8	Weak-field ligands	I^-, Br^-, Cl^-, F^-	132
9	Inner-orbital complex	d^2sp^3 low-spin (e.g. $[Co(NH_3)_6]^{3+}$)	129
10	Outer-orbital complex	sp^3d^2 high-spin (e.g. $[CoF_6]^{3-}$)	129
11	Square planar examples	$[Ni(CN)_4]^{2-}$, $[PtCl_4]^{2-}$	131
12	Tetrahedral examples	$[NiCl_4]^{2-}$, $[MnBr_4]^{2-}$	131
13	Cis-trans isomerism	Octahedral MA_4B_2 & square planar MA_2B_2	126
14	Optical isomerism	$[Co(en)_3]^{3+}$, cis-$[Co(en)_2Cl_2]^+$	127
15	Biological complexes	Haemoglobin (Fe-porphyrin), chlorophyll (Mg-porphyrin), B_{12} (Co), cisplatin (Pt)	138

🎯 Practice MCQs

Q1. According to Werner's theory of coordination compounds, the secondary valence of a metal is equal to its:

A. Primary valence

B. Oxidation state

C. Coordination number

D. Atomic number

Q2. Which of the following pairs correctly identifies the type of ligand?

A. NH_3 — bidentate

B. $C_2O_4^{2-}$ — unidentate

C. $EDTA^{4-}$ — hexadentate

D. en (ethane-1,2-diamine) — ambidentate

Q3. The IUPAC name of $K_3[Fe(C_2O_4)_3]$ is:

A. Potassium trioxalatoferrate(III)

B. Potassium trioxalatoferrate(II)

C. Tripotassium trioxalatoiron(III)

D. Potassium trioxalatoiron(II)

📊 PYQ Alignment

Coordination Compounds is among the highest-yielding chapters in the CUET (UG) Chemistry paper, with roughly 12–15 MCQs across recent 2023-25 papers. NTA favours IUPAC nomenclature (especially anionic complexes with "-ate" suffix), oxidation-state calculation in formulae like $K_3[Fe(C_2O_4)_3]$, identification of isomerism types (linkage/ionisation/cis-trans/optical), VBT hybridisation/magnetic-moment predictions for first-row transition complexes, octahedral CFSE / strong-vs-weak-field reasoning, the

spectrochemical series order, and biological-importance one-liners (chlorophyll-Mg, haemoglobin-Fe, B_{12}-Co, cisplatin-Pt).

CUET 2025 — Actual PYQs from this chapter

Q.20 (CUET 2025) Select correct statements for $[Fe(CN)_6]^{3-}$ complex: (A) Paramagnetic (B) sp^3d^2 hybridization (C) Magnetic moment = 5.92 BM (D) d^2sp^3 hybridization

- A) — B) — C) — D) —

Tests: Coordination — VBT/magnetism Answer: Not in extracted key

CUET 2024 — Actual PYQs from this chapter

Q.8 (CUET 2024) Which compound will be repelled in an external magnetic field?

- A) $Na_2[CuCl_4]$ B) $Na_2[CdCl_4]$ C) $K_4[Fe(CN)_6]$ D) $K_3[Fe(CN)_6]$

Tests: Coordination Compounds Answer: Not in extracted key

Q.9 (CUET 2024) Spin-only magnetic moment of $[Mn(CN)_6]^{4-}$ is:

- A) 5.90 BM B) 1.73 BM C) 4.90 BM D) 3.87 BM

Tests: Coordination — VBT/magnetism Answer: Not in extracted key

Q.1 (CUET 2024) The total number of ions produced from the complex $[Cr(NH_3)_6]Cl_3$ in aqueous solution will be:

- A) 2 B) 3 C) 4 D) 5

Tests: Coordination — ionisation in aqueous solution Answer: Not in extracted key

CUET 2023 — Actual PYQs from this chapter

Q.41 (CUET 2023) Two complexes of nickel having same geometry but different magnetic behaviour are: (A) $[Ni(CN)_4]^{2-}$ (B) $[Ni(CO)_4]$ (C) $[NiCl_4]^{2-}$ (D) $[Ni(NH_3)_6]^{2+}$ Options:

- A) (A) and (B) only B) (B) and (D) only C) (B) and (C) only D) (A) and (D) only

Tests: Coordination Compounds Answer: Not in extracted key

Q.43 (CUET 2023) Among the following, which should have the highest magnetic moment?

- A) $[NiCl_4]^{2-}$ B) $[Mn(CN)_6]^{4-}$ C) $[Cr(NH_3)_6]^{3+}$ D) $[CoF_6]^{3-}$

Tests: Coordination — VBT/magnetism Answer: Not in extracted key

Q.44 (CUET 2023) The compound $[Pt(NH_3)_2Cl_2]$ exhibits:

- A) Geometrical isomerism B) Linkage isomerism C) Ionisation isomerism D) Coordination isomerism

Tests: Coordination Compounds Answer: Not in extracted key

Q.42 (CUET 2023) Which complexes are correctly matched with hybridisation?

- A) $[Ni(H_2O)_6]^{2+}$ – sp^3d^2 B) $[CoF_6]^{3-}$ – sp^3d^2 C) $[Cu(NH_3)_4]^{2+}$ – dsp^2 D) $[MnCl_4]^{2-}$ – dsp^2

Tests: Coordination — hybridisation of complexes Answer: Not in extracted key