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CHAPTER NOTES

# Coordination Compounds Class 12 Notes — CBSE Chemistry Chapter 9

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# Coordination Compounds Class 12 Notes — CBSE Chemistry Chapter 9

Chapter 9 — **Coordination Compounds** — introduces the fascinating world of metal complexes. From haemoglobin in your blood to cisplatin in cancer treatment, coordination compounds are everywhere! This chapter carries **5-7 marks** in Board exams. Focus on IUPAC naming, isomerism, and bonding theories (VBT and CFT).

## Key Concepts

### Basic Terminology

| Term | Meaning | Example |
|---|---|---|
| Central metal atom/ion | Metal that accepts electron pairs | $Cu^{2+}$ in $[Cu(NH_3)_4]^{2+}$ |
| Ligand | Ion/molecule that donates electron pair to metal | $NH_3$, $Cl^-$, $H_2O$, $CN^-$ |
| Coordination number (CN) | Number of ligand donor atoms bonded to metal | CN = 6 in $[Co(NH_3)_6]^{3+}$ |
| Coordination sphere | Central metal + ligands (written in square brackets) | $[Fe(CN)_6]^{4-}$ |
| Counter ion | Ion outside the coordination sphere | $K^+$ in $K_4[Fe(CN)_6]$ |
| Denticity | Number of donor atoms in a ligand | en (ethylenediamine) = bidentate |

### Types of Ligands

| Type | Donor Atoms | Examples |
|---|---|---|
| Monodentate | 1 | $H_2O$, $NH_3$, $Cl^-$, $CN^-$, $NO_2^-$, CO |
| Bidentate | 2 | en (ethylenediamine), $ox^{2-}$ (oxalate, $C_2O_4^{2-}$) |
| Polydentate | Many | $EDTA^{4-}$ (hexadentate — 6 donor atoms) |
| Ambidentate | 1 (but 2 possible donor atoms) | $NO_2^-$ (N or O), $SCN^-$ (S or N) |

**Chelate Effect:** Complexes with polydentate ligands (chelating agents like EDTA) are more stable than those with monodentate ligands. This is because the chelate "grabs" the metal from multiple points — like a claw (Greek: chele = claw).

## IUPAC Nomenclature Rules

1. Cation is named first, then anion (even if complex is the anion)
2. Ligands are named alphabetically (ignoring prefixes di-, tri-)
3. Anionic ligands: suffix **-o** (chlorido, cyanido, hydroxido, oxalato)
4. Neutral ligands: usual name, EXCEPT: $H_2O$ = **aqua**, $NH_3$ = **ammine**, CO = **carbonyl**, NO = **nitrosyl**
5. Metal in anionic complex: suffix **-ate** (ferrate, cuprate, cobaltate)
6. Oxidation state of metal in Roman numerals in parentheses: (III), (II)

### Naming Examples

$[Co(NH_3)_6]Cl_3$ → **Hexaamminecobalt(III) chloride**

$K_3[Fe(CN)_6]$ → **Potassium hexacyanidoferrate(III)**

$[CoCl_2(en)_2]Cl$ → **Dichloridobis(ethylenediamine)cobalt(III) chloride**

$[Pt(NH_3)_2Cl_2]$ → **Diamminedichloridoplatinum(II)** (cisplatin — anticancer drug!)

## Isomerism in Coordination Compounds

### Structural Isomerism

| Type | Description | Example |
|---|---|---|
| Ionisation | Exchange of ligand and counter ion | $[Co(NH_3)_5Br]SO_4$ vs $[Co(NH_3)_5SO_4]Br$ |
| Linkage | Ambidentate ligand bonds through different atoms | $[Co(NH_3)_5ONO]^{2+}$ vs $[Co(NH_3)_5NO_2]^{2+}$ |
| Coordination | Exchange of ligands between cation and anion | $[Co(NH_3)_6][Cr(CN)_6]$ vs $[Cr(NH_3)_6][Co(CN)_6]$ |
| Solvate/Hydrate | Water as ligand vs as lattice water | $[Cr(H_2O)_6]Cl_3$ vs $[Cr(H_2O)_5Cl]Cl_2 \cdot H_2O$ |

## Stereoisomerism

**Geometrical (cis-trans):** In square planar (CN=4) and octahedral (CN=6) complexes

- Square planar $[MA_2B_2]$: cis (same side) and trans (opposite)
- Octahedral $[MA_2B_4]$: cis and trans
- $[MA_3B_3]$ octahedral: fac (facial — same triangular face) and mer (meridional — same plane)

**Optical isomerism:** Non-superimposable mirror images (d and l forms)

- Common in octahedral complexes with bidentate ligands: $[Co(en)_3]^{3+}$
- Also in cis-$[CoCl_2(en)_2]^+$ (cis shows optical isomerism, trans doesn't)

# Bonding Theories

## Valence Bond Theory (VBT)

**Key Ideas:**

1. Ligands donate electron pairs to empty hybrid orbitals of metal
2. Inner orbital complex: uses (n−1)d orbitals → diamagnetic/low spin
3. Outer orbital complex: uses nd orbitals → paramagnetic/high spin

**Common Hybridisations:**

CN=4: $sp^3$ (tetrahedral) or $dsp^2$ (square planar)

CN=6: $d^2sp^3$ (inner, octahedral) or $sp^3d^2$ (outer, octahedral)

## Crystal Field Theory (CFT)

**Key Ideas:**

1. Ligands are treated as point charges that create an electrostatic field
2. This field splits d-orbitals into two sets:

**Octahedral:** $t_2g$ ($dxy$, $dxz$, $dyz$) ↓ lower energy and eg ($dx^2-y^2$, $dz^2$) ↑ higher energy

Energy gap = $\Delta_0$ (crystal field splitting energy)

**Tetrahedral:** e ($dx^2-y^2$, $dz^2$) ↓ lower and $t_2$ ($dxy$, $dxz$, $dyz$) ↑ higher

$\Delta t \approx 4/9\ \Delta_0$ (always smaller → tetrahedral are high spin)

## Spectrochemical Series (increasing Δ)

$I^- < Br^- < S^{2-} < Cl^- < N_3^- < F^- < OH^- < ox^{2-} < H_2O < NCS^- < CH_3CN < py < NH_3 < en < bipy < phen < NO_2^- < PPh_3 < CN^- < CO < NO^+$

**Weak field ligands** ($I^-$, $Br^-$, $Cl^-$, $F^-$) → small Δ → high spin complexes

**Strong field ligands** ($CN^-$, CO, $NO_2^-$, en, $NH_3$) → large Δ → low spin complexes

## CFSE (Crystal Field Stabilisation Energy)

**CFSE = $(-0.4n\_t_2g + 0.6n\_eg)\Delta_0$ + pairing energy corrections**

Where n = number of electrons in each set

## Applications of Coordination Compounds

- **Haemoglobin:** $Fe^{2+}$ coordination compound that carries $O_2$ in blood
- **Chlorophyll:** $Mg^{2+}$ coordination compound for photosynthesis
- **Vitamin $B_{12}$:** $Co^{3+}$ coordination compound
- **Cisplatin:** cis-$[Pt(NH_3)_2Cl_2]$ — anticancer drug
- **EDTA:** Used in water softening, treatment of lead poisoning
- **Photography:** AgBr dissolved by $Na_2[Ag(S_2O_3)_2]$ (fixing)

## Important Definitions

| Term | Definition |
|---|---|
| Coordination Compound | Compound containing a central metal bonded to ligands via coordinate bonds |
| Ligand | Atom/ion/molecule that donates electron pair to central metal |
| Coordination Number | Number of donor atoms directly bonded to the central metal |
| Chelate | Complex containing polydentate ligand forming a ring with the metal |
| Crystal Field Splitting | Splitting of d-orbitals into different energy levels due to ligand field |
| Spectrochemical Series | Arrangement of ligands in order of increasing crystal field splitting |

## Solved Examples — NCERT Based

### Example 1: IUPAC Naming

**Q:** Write IUPAC names: (a) $[Cr(NH_3)_3(H_2O)_3]Cl_3$ (b) $[CoCl_2(en)_2]^+$ (c) $K_2[PdCl_4]$

**Solution:**

(a) **Triamminetriaquachromium(III) chloride**

(b) **Dichloridobis(ethylenediamine)cobalt(III) ion**

(c) **Potassium tetrachloridopalladate(II)**

### Example 2: Finding Oxidation State and CN

**Q:** In $K_3[Fe(CN)_6]$, find the oxidation state of Fe and coordination number.

**Solution:**

Let oxidation state of Fe = x

$3(+1) + x + 6(-1) = 0 \rightarrow 3 + x - 6 = 0 \rightarrow x =$ **+3**

Coordination number = number of $CN^-$ ligands = **6** (each $CN^-$ is monodentate)

### Example 3: CFT — Predicting Colour

**Q:** $[Ti(H_2O)_6]^{3+}$ appears purple. Explain using CFT.

**Solution:**

$Ti^{3+}$ = [Ar] $3d^1$ → one electron in $t_2g$ level. When visible light passes through, the electron absorbs green-yellow light (corresponding to $\Delta_0$) and jumps from $t_2g$ to eg. The transmitted/reflected light (purple, the complement of green-yellow) is what we see. This is a **d-d transition**.

### Example 4: Magnetic Properties from CFT

**Q:** Predict whether $[Fe(CN)_6]^{4-}$ is paramagnetic or diamagnetic.

**Solution:**

$Fe^{2+}$ = $3d^6$. $CN^-$ is a **strong field ligand** → large $\Delta_0$ → electrons pair up before going to eg.

$t_2g^6$ $eg^0$ → all electrons paired → **diamagnetic** (0 unpaired electrons).

Compare: $[Fe(H_2O)_6]^{2+}$ with weak field $H_2O$ → $t_2g^4$ $eg^2$ → 4 unpaired → paramagnetic.

## Important Questions for Board Exams

### 1 Mark Questions

1. What is the coordination number in $[Co(NH_3)_6]^{3+}$?
2. What is an ambidentate ligand? Give an example.
3. Write the IUPAC name of $[Pt(NH_3)_2Cl_2]$.
4. What is the oxidation state of Co in $[Co(CN)_6]^{3-}$?

### 2 Mark Questions

1. What is the difference between a double salt and a coordination compound?
2. Explain geometrical isomerism in $[Pt(NH_3)_2Cl_2]$ with diagrams.

3. What is meant by chelation? Why are chelate complexes more stable?
4. Write the spectrochemical series for 5 common ligands.

## 3 Mark Questions

1. Explain Crystal Field Theory for octahedral complexes. What is crystal field splitting?
2. Using VBT, predict the hybridisation and magnetic property of $[Fe(CN)_6]^{4-}$ and $[FeF_6]^{3-}$.
3. What are the different types of isomerism shown by coordination compounds? Give one example each.
4. What is spectrochemical series? How does it help predict magnetic properties?

## 5 Mark Questions

1. What is CFT? Explain crystal field splitting in octahedral and tetrahedral complexes. Why are most tetrahedral complexes high spin?
2. Discuss the Werner's theory of coordination compounds. Write IUPAC names and describe the isomerism of $[CoCl_2(en)_2]^+$.

# Quick Revision Points

- Ligands: monodentate (1 donor), bidentate (2: en, ox), polydentate (EDTA = 6)
- IUPAC: ligands alphabetical, anionic = -o, neutral = name ($H_2O$=aqua, $NH_3$=ammine)
- Structural isomers: ionisation, linkage, coordination, solvate
- Stereoisomers: geometrical (cis-trans, fac-mer) and optical (d, l)
- VBT: $sp^3$ (tetrahedral), $dsp^2$ (square planar), $d^2sp^3/sp^3d^2$ (octahedral)
- CFT: octahedral splits into $t_2g$ (lower) and eg (higher); $\Delta_0$
- Strong field → large Δ → low spin → paired → diamagnetic
- Weak field → small Δ → high spin → unpaired → paramagnetic
- Spectrochemical series: $I^- < Br^- < Cl^- < F^- < H_2O < NH_3 < en < CN^- < CO$
- Cisplatin [cis-$Pt(NH_3)_2Cl_2$] = anticancer; Hb = $Fe^{2+}$ complex; chlorophyll = $Mg^{2+}$

← Previous: d- and f-Block Elements

Next: Haloalkanes and Haloarenes →