▶ Video explanation (YouTube Short)

Formation of Complex Compounds: Why Transition Metals Form Complexes

Add one drop of potassium thiocyanate (KSCN) to a pale-yellow solution of Fe^{3+} and it turns blood red at once. A new species has formed around the iron ion, while the K^+ ion that came in the same drop builds nothing. These notes explain what a complex is and why transition-metal ions form so many of them (NCERT 4.3.11).

1. What is a complex?

- **Complex compounds** are those in which a **metal ion binds a number of anions or neutral molecules**, giving complex species with characteristic properties (NCERT).
- The molecules or ions bound to the metal are called **ligands** (e.g. H_2O, NH_3, CN^-, Cl^-, SCN^-).
- The complex is written in square brackets with its overall charge: **$[Fe(CN)_6]^{3-}$**, **$[Fe(CN)_6]^{4-}$**, **$[Cu(NH_3)_4]^{2+}$**, **$[PtCl_4]^{2-}$**.

The blood-red test: $[Fe(H_2O)_6]^{3+} + SCN^- \rightarrow [Fe(SCN)(H_2O)_5]^{2+} + H_2O$. One SCN^- replaces one water ligand; the blood-red complex is the standard test for Fe^{3+}. K^+ is only a spectator.

2. How the bond forms: the coordinate bond

1. Every ligand has at least one **lone pair** of electrons (for example on N of NH_3, on N of SCN^-, on O of H_2O).
2. The metal ion has **orbitals available for bonding** (NCERT: "availability of d orbitals for bond formation").
3. The ligand donates its whole lone pair into such an orbital. Both electrons of the bond come from the ligand: this is a **coordinate (dative) bond**, drawn as L → M.

3. Why transition-metal ions form so many complexes

Reason (NCERT)	What it means	Example
1. Comparatively small size	The ligand's lone pair can come close to the nucleus of the metal ion	Fe^{3+} 65 pm vs K^+ 138 pm
2. High ionic charge	A large positive charge pulls strongly on the lone pair	Fe^{3+} (+3) vs K^+ (+1)
3. d orbitals available for bond formation	The ion can accept electron pairs into its available orbitals	Fe, Co, Ni, Cu, Pt ions

Reasons 1 and 2 together mean a high **charge density** (charge ÷ size). For Fe^{3+} the charge ÷ radius is 3 ÷ 65 ≈ 0.046; for K^+ it is 1 ÷ 138 ≈ 0.0072: about **6 times** smaller. (Radii: Shannon effective ionic radii, six-coordinate.)

4. Worked examples

Example 1

Why does Fe^{3+} form complexes more readily than Fe^{2+}? Fe^{3+} is smaller (65 pm vs 78 pm) and has a higher charge (+3 vs +2), so it attracts a ligand's lone pair more strongly.

Example 2

In $[Cu(NH_3)_4]^{2+}$, identify the central ion, the ligands and the bond type. Central ion Cu^{2+}; ligands four NH_3 molecules (each donates the lone pair on N); bonds are coordinate bonds N → Cu. The complex is deep blue.

Example 3

Charge of the complex: $[Fe(CN)_6]$: Fe^{3+} (+3) + 6 CN^- (−6) = −3, so $[Fe(CN)_6]^{3-}$. With Fe^{2+}: +2 − 6 = −4, so $[Fe(CN)_6]^{4-}$.

Example 4

Complexes in life: **haemoglobin** carries O_2 bound to iron held in a ring of four N atoms (haem); **cisplatin** $[PtCl_2(NH_3)_2]$ is an anticancer drug; vitamin B_{12} contains cobalt.

5. Common mistakes

- ✗ "In a coordinate bond each atom gives one electron." ✓ Both electrons come from the ligand.
- ✗ "Only transition metals form complexes." ✓ Other ions (e.g. Al^{3+}, Mg^{2+} in chlorophyll) can, but transition-metal ions form far more.
- ✗ "A complex is just a complicated compound." ✓ It is a central metal ion with ligands bonded to it by coordinate bonds.
- ✗ "Bigger ions hold ligands better." ✓ Smaller, more highly charged ions hold them better.

6. Key takeaways

- Complex = central metal ion + ligands joined by coordinate bonds (both electrons from the ligand).
- Transition metals form many complexes because their ions are small, highly charged and have d orbitals available for bonding.
- Details (naming, isomerism, bonding theories) come in Unit 5, Coordination Compounds.

Practice questions

1. (MCQ) In a coordinate bond the shared electron pair comes from: (a) the metal (b) the ligand (c) both, one each (d) the solvent
2. (MCQ) Which is NOT a reason transition metals form complexes? (a) small ion size (b) high ionic charge (c) available d orbitals (d) low density of the metal
3. (MCQ) Which ion is expected to form complexes most readily? (a) K^+ (b) Na^+ (c) Fe^{3+} (d) Cs^+
4. (MCQ) The charge on the complex formed by Fe^{2+} and six CN^- is: (a) −3 (b) −4 (c) +2 (d) −6
5. (Very short) What is a ligand?
6. (Very short) Name the complex formed in the Fe^{3+} thiocyanate test.
7. (Short) Explain why Fe^{3+} forms complexes more readily than K^+.

8. (Short) What is a coordinate bond? Give one example.
9. (Short) Identify the central ion and ligands in $[PtCl_4]^{2-}$.
10. (NCERT 4.3.11 type) Give three reasons why transition metals form a large number of complex compounds.

Answer key

1. (b) the ligand.
2. (d).
3. (c) Fe^{3+}: small and +3.
4. (b) $+2 - 6 = -4$: $[Fe(CN)_6]^{4-}$.
5. An ion or molecule that donates a lone pair to a central metal ion in a complex.
6. $[Fe(SCN)(H_2O)_5]^{2+}$ (blood red).
7. Fe^{3+} is much smaller (65 pm vs 138 pm) and more highly charged (+3 vs +1), so it pulls a ligand's lone pair strongly; it also has d orbitals available to accept the pair.
8. A bond in which both shared electrons come from one atom (the donor); e.g. $NH_3 \rightarrow Cu^{2+}$ in $[Cu(NH_3)_4]^{2+}$.
9. Central ion Pt^{2+}; four Cl^- ligands.
10. Comparatively small size of the ions, their high ionic charges, and the availability of d orbitals for bond formation.

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