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FSc / ICS Part-II Chemistry — Punjab Board

CHAPTER 6

Transition Elements

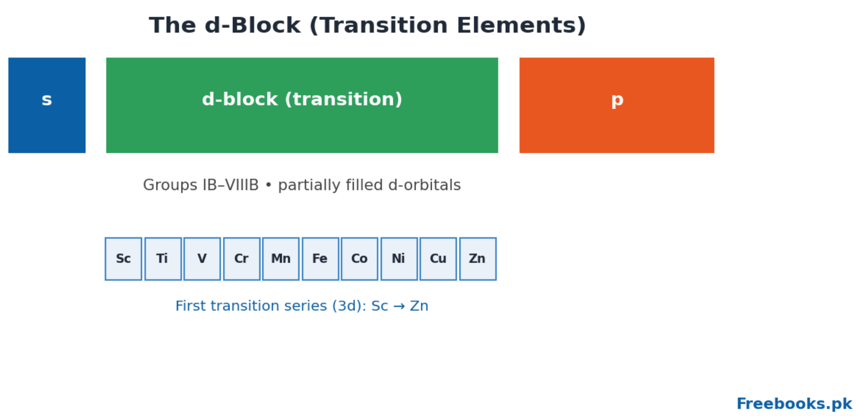

Figure 6.1 — The d-block transition elements sit between the s- and p-blocks.

1. Chapter Overview

The transition elements are the d-block metals that lie in the middle of the periodic table, between Groups IIA and IIIA. They are defined as elements whose atoms or common ions have partially filled d-orbitals. The first transition series runs from scandium to zinc (Sc → Zn). These metals are the 'workhorses' of chemistry and industry: iron, copper, chromium, nickel and their alloys build our machines, tools and coins, and their compounds give the bright colours seen in gemstones, paints and laboratory solutions.

The transition metals share a set of striking properties — variable oxidation states, coloured ions, catalytic activity, magnetic behaviour and the formation of complex (coordination) compounds — all of which come from their partly filled d-orbitals.

2. Learning Objectives

- Define transition elements and give the first transition series.
- Write the electronic configurations of first-series transition metals and their ions.
- Explain why transition metals show variable oxidation states.
- Explain why their ions are coloured and many are paramagnetic.
- Explain their catalytic activity and the formation of complex ions.
- Define ligand, coordination number and complex, with examples.
- State important uses and alloys of transition metals.

3. Key Concepts

3.1 What Makes an Element a Transition Element?

A transition element is one whose atom or a stable ion has an incompletely filled d-subshell. On this strict definition, zinc is not a true transition metal because its ion Zn^{2+} has a completely filled $3d^{10}$ configuration; it is called a d-block element but not a typical transition metal. The first (3d) series is: Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn.

> **Memory Trick**
> **First series:** “Scientist Ti V Cr Mn Fe Co Ni Cu Zinc” — Sc Ti V Cr Mn Fe Co Ni Cu Zn.
> **Odd ones out:** Cr = $[Ar]3d^5 4s^1$ and Cu = $[Ar]3d^{10} 4s^1$ (half-filled / filled d is extra stable).

3.2 General Characteristics

Metallic and hard. They are hard, strong, high-melting metals with high densities because both 3d and 4s electrons take part in strong metallic bonding.

Variable oxidation states. Because the 3d and 4s energy levels are very close, a variable number of electrons can be used in bonding, so most transition metals show several oxidation states (e.g. iron as +2 and +3; manganese from +2 up to +7).

Coloured ions. Most transition-metal ions are coloured. When light falls on them, electrons jump between split d-orbitals (d–d transitions), absorbing part of the visible light; the colour we see is the remaining light. For example Cu^{2+} is blue and MnO_4^- is purple.

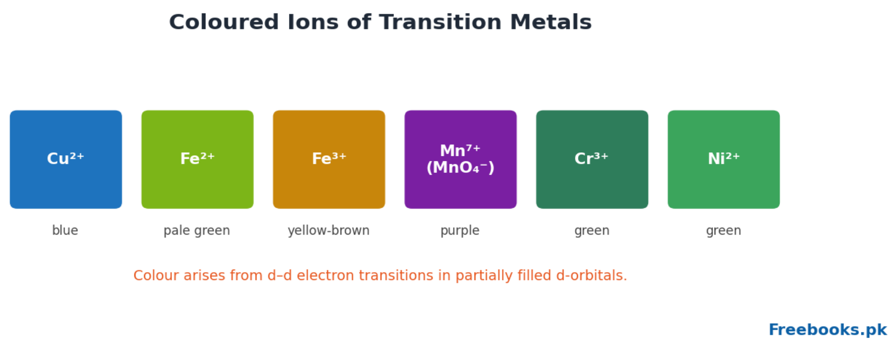

Figure 6.2 — Characteristic colours of some transition-metal ions.

Paramagnetism. Ions with unpaired d-electrons are attracted by a magnetic field (paramagnetic); the more unpaired electrons, the stronger the effect.

Catalytic activity. Transition metals and their compounds are excellent catalysts (e.g. Fe in the Haber process, V_2O_5 in the Contact process, Ni in hydrogenation) because they offer variable oxidation states and surfaces on which reactants can adsorb.

3.3 Complex (Coordination) Compounds

A special feature of transition metals is their ability to form complex ions, in which a central metal ion is surrounded by a number of molecules or ions called ligands, each donating a lone pair of electrons to the metal (a coordinate/dative bond). The number of ligand atoms directly bonded to the metal is the coordination number.

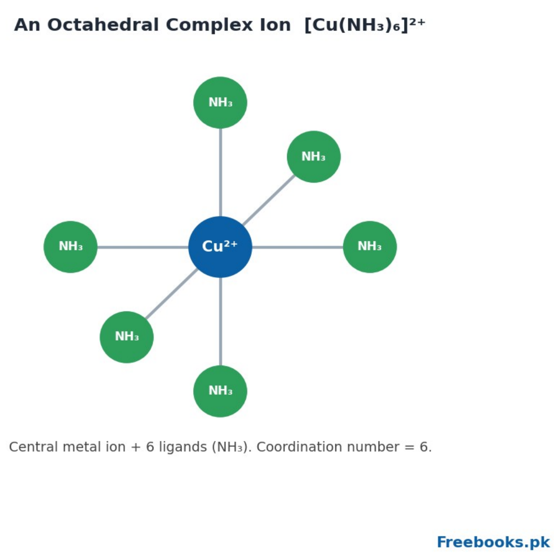

Figure 6.3 — An octahedral complex ion, $[Cu(NH_3)_6]^{2+}$ (coordination number 6).

Complex Ion Vocabulary

Ligand: a molecule or ion (e.g. NH_3, H_2O, CN^-, Cl^-) that donates a lone pair to the metal.
Coordination number: the number of ligand atoms bonded to the central metal ion (commonly 4 or 6).
Examples: $[Cu(NH_3)_4]^{2+}$ (deep blue), $[Fe(CN)_6]^{3-}$, $[Ag(NH_3)_2]^+$.

Teacher's Note

Ask students to always identify three things in any complex: the central metal, the ligands, and the coordination number. This makes naming and understanding complexes much easier.

3.4 Alloys and Uses

Transition metals are widely used both as pure metals and as alloys. Iron is turned into steel (with carbon) and stainless steel (with chromium and nickel); copper is used in wiring and, with zinc, forms brass; chromium and nickel are used for electroplating and corrosion-resistant coatings; and silver, gold and platinum are prized in jewellery, electronics and as catalysts.

4. Important Definitions

Term	Definition
Transition element	An element whose atom or stable ion has a partially filled d-subshell.
Ligand	A molecule or ion that donates a lone pair to a central metal ion in a complex.
Coordination number	The number of ligand atoms directly bonded to the central metal ion.
Complex ion	A central metal ion bonded to a definite number of ligands by coordinate bonds.
Paramagnetism	Attraction to a magnetic field due to unpaired electrons.
Catalyst	A substance that speeds up a reaction without being consumed.

5. Formulas / Rules

Must-Know Facts

First transition series: Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn (3d).
Anomalous configs: Cr = $3d^5 4s^1$, Cu = $3d^{10} 4s^1$.
Colour cause: d–d electronic transitions in partly filled d-orbitals.
Key catalysts: Fe (Haber), V_2O_5 (Contact), Ni (hydrogenation), Pt.
Common coordination numbers: 4 (tetrahedral/square planar) and 6 (octahedral).

6. Diagrams / Illustrations

Key diagrams for revision:

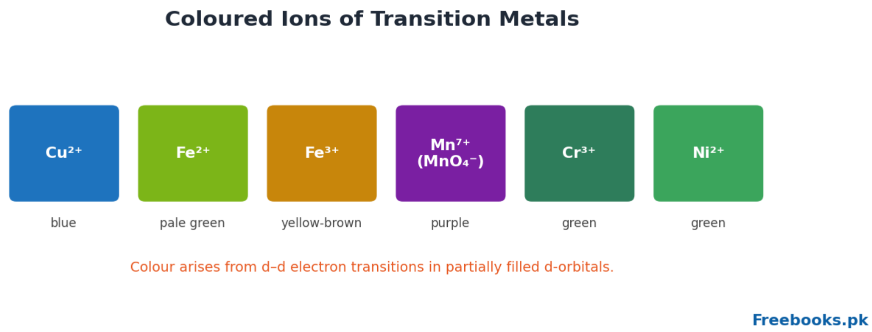

Diagram 1 — Coloured transition-metal ions.

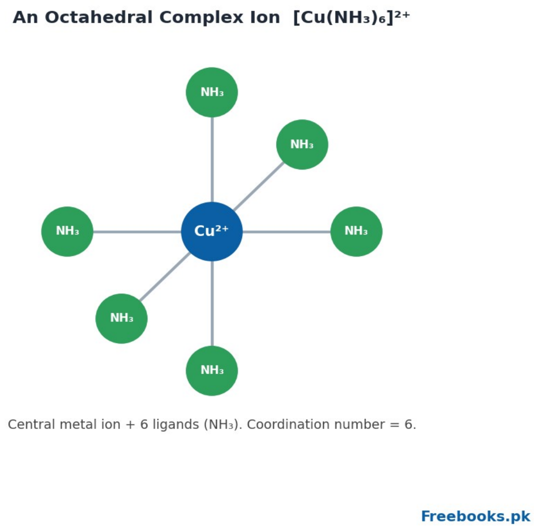

Diagram 2 — Octahedral complex ion.

7. Solved Examples

Example 1 — Variable oxidation states

Q: Give two oxidation states of iron and one compound of each.

Solution: Iron shows +2 (as in $FeSO_4$, iron(II) sulphate) and +3 (as in $FeCl_3$, iron(III) chloride). This is possible because the 3d and 4s electrons have similar energies.

Example 2 — Identifying a complex

Q: In $[Cu(NH_3)_4]^{2+}$, name the central ion, the ligand and the coordination number.

Solution: Central ion = Cu^{2+}; ligand = NH_3 (ammonia); coordination number = 4.

Example 3 — Colour

Q: Why is the Zn^{2+} ion colourless while Cu^{2+} is blue?

Solution: Zn^{2+} has a completely filled $3d^{10}$ shell, so no d–d transition is possible and it is colourless. Cu^{2+} has a partly filled d-shell, so d–d transitions absorb light and it appears blue.

8. Short Questions

Q1. Define a transition element.
Ans. An element whose atom or a stable ion has a partially filled d-subshell.

Q2. Why is zinc not a typical transition metal?
Ans. Its ion Zn^{2+} has a completely filled $3d^{10}$ configuration, so it lacks a partly filled d-shell.

Q3. Why do transition metals show variable oxidation states?
Ans. Because their 3d and 4s energy levels are close, so different numbers of electrons can be used in bonding.

Q4. Why are transition-metal ions coloured?
Ans. Because electrons undergo d–d transitions in partly filled d-orbitals, absorbing part of visible light.

Q5. What is a ligand?
Ans. A molecule or ion that donates a lone pair of electrons to a central metal ion in a complex.

Q6. Define coordination number.
Ans. The number of ligand atoms directly bonded to the central metal ion.

Q7. Give two transition metals used as catalysts.
Ans. Iron (Haber process) and nickel (hydrogenation of oils).

Q8. Why are many transition-metal ions paramagnetic?
Ans. Because they contain unpaired d-electrons that are attracted to a magnetic field.

9. Long Questions

Q1. Describe the general characteristic properties of the transition elements.

The transition elements are d-block metals with partially filled d-orbitals, and this single feature explains their special properties. They are hard, dense, high-melting metals because both their 3d and 4s electrons take part in strong metallic bonding. Because these two energy levels are very close, a variable number of electrons can be used in bonding, so the metals show several oxidation states (for example iron +2 and +3, manganese +2 to +7). Their ions are usually coloured, because electrons move between split d-orbitals (d–d transitions) and absorb part of the visible light. Ions with unpaired d-electrons are paramagnetic. The metals and their compounds are excellent catalysts, offering variable oxidation states and active surfaces. Finally, their small, highly charged ions readily accept lone pairs from ligands to form stable complex (coordination) compounds.

Q2. What are complex compounds? Explain with reference to ligands and coordination number.

A complex (or coordination) compound contains a complex ion, in which a central transition-metal ion is bonded to a definite number of surrounding molecules or ions called ligands. Each ligand possesses at least one lone pair of electrons, which it donates to the metal ion to form a coordinate (dative) bond; common ligands are water, ammonia, chloride ions and cyanide ions. The number of ligand atoms directly attached to the central metal is called the coordination number, which is most often 4 (giving tetrahedral or square-planar shapes) or 6 (giving an octahedral shape). For example, in $[Cu(NH_3)_6]^{2+}$ the central Cu^{2+} ion is surrounded by six ammonia ligands, giving a coordination number of 6 and an octahedral shape. Transition metals form such complexes readily because their small, highly charged ions with empty d-orbitals can accept the lone pairs of ligands.

Q3. Explain, with examples, the catalytic activity and important uses of transition metals.
Transition metals and their compounds are among the best catalysts known. They work well because they can exist in more than one oxidation state (providing an easy path for electron transfer) and because reactant molecules can be adsorbed and activated on their metal surfaces. Familiar examples are iron in the Haber process for ammonia, vanadium(V) oxide in the Contact process for sulphuric acid, nickel in the hydrogenation of vegetable oils into ghee, and platinum in catalytic converters. Beyond catalysis, transition metals are indispensable materials: iron and steel build machinery and structures, stainless steel (iron with chromium and nickel) resists rust, copper carries electricity and forms brass and bronze, and chromium and nickel are used for protective, decorative electroplating.

10. Multiple Choice Questions (MCQs)

1. Transition elements belong to the:
(A) s-block (B) p-block (C) d-block (D) f-block

2. Which ion is colourless?
(A) Cu^{2+} (B) Fe^{3+} (C) Zn^{2+} (D) Mn^{2+}

3. The colour of transition-metal ions is due to:
(A) s–s transitions (B) d–d transitions (C) nuclear changes (D) ionic bonding

4. The electronic configuration of chromium is:
(A) $[Ar]3d^4 4s^2$ (B) $[Ar]3d^5 4s^1$ (C) $[Ar]3d^6$ (D) $[Ar]3d^3 4s^2$

5. In $[Cu(NH_3)_4]^{2+}$ the coordination number is:
(A) 2 (B) 4 (C) 6 (D) 8

6. A ligand is a species that:
(A) accepts electrons (B) donates a lone pair (C) forms ionic bonds (D) is always neutral

7. Which is used as a catalyst in the Haber process?
(A) Ni (B) Fe (C) V_2O_5 (D) Pt

8. Paramagnetism is caused by:
(A) paired electrons (B) unpaired electrons (C) protons (D) neutrons

9. Which metal is NOT a typical transition metal?
(A) Fe (B) Cu (C) Zn (D) Cr

10. The purple colour of $KMnO_4$ is due to:
(A) Mn^{2+} (B) MnO_4^- (C) K^+ (D) O^{2-}

MCQ Answer Key
1-C 2-C 3-B 4-B 5-B 6-B 7-B 8-B 9-C 10-B

11. Quick Revision / Summary

- Transition metals = d-block with partly filled d-orbitals; first series Sc → Zn.
- Zn is not a typical transition metal ($3d^{10}$).
- Key properties: variable oxidation states, coloured ions, paramagnetism, catalysis, complexes.
- Colour = d–d transitions; Zn^{2+} colourless (filled d).
- Complex = central metal + ligands; coordination number = ligand atoms bonded.
- Catalysts: Fe (Haber), V_2O_5 (Contact), Ni (hydrogenation).

12. Exam Tips

Teacher's Note

Link every transition property back to 'partly filled d-orbitals'.

Remember Cr ($3d^5 4s^1$) and Cu ($3d^{10} 4s^1$) exceptions — common MCQ.

For colour questions, always mention d–d transitions; Zn^{2+}/Sc^{3+} are colourless (no partly filled d).

In any complex, state central metal + ligand + coordination number.

Know the standard catalysts and the process each is used in.