▶ Video explanation (YouTube Short)

Catalytic Properties: Why Transition Metals Are Good Catalysts

About 78 % of air is nitrogen, yet N_2 hardly reacts: its N≡N triple bond is very strong. Even hot (≈ 450 °C) and under pressure, N_2 and H_2 give almost no ammonia, until finely divided iron is added. These notes explain how transition metals and their compounds act as catalysts (NCERT 4.3.12).

1. What is a catalyst?

- A **catalyst** increases the rate of a reaction and is **not used up**: it is present in the same amount and form at the end.
- It works by providing an easier path with a **lower activation energy (E_a)**. It adds no energy and does not change ΔH or the equilibrium position; it only helps equilibrium be reached faster.
- NCERT: transition metals and their compounds are known for their catalytic activity, ascribed to their ability to **adopt multiple oxidation states** and to **form complexes**.

2. Reason 1: bonding at the catalyst surface

1. Reactant molecules form **bonds with atoms on the metal surface**. First-row transition metals use their **3d and 4s electrons** for this bonding.
2. Effect 1: the **concentration of reactants at the surface increases**: molecules are held close together.
3. Effect 2: the **bonds in the reacting molecules weaken** (e.g. N≡N in N_2, H–H in H_2).
4. Result: the **activation energy is lowered** and the reaction is faster. The products then leave the surface, which is free again.

This is called heterogeneous catalysis: the catalyst (a solid) is in a different phase from the reactants (gases or liquids). That is why the iron is used **finely divided**: more surface area, more sites.

3. Catalysts in industry (NCERT examples)

Process	Catalyst	Reaction	Product used for
Haber process	finely divided iron (Fe)	$N_2 + 3H_2 \rightleftharpoons 2NH_3$	ammonia → fertilisers
Contact process	vanadium(V) oxide, V_2O_5	$2SO_2 + O_2 \rightleftharpoons 2SO_3$	sulphuric acid
Catalytic hydrogenation	nickel (Ni)	vegetable oil + H_2 → solid fat	vanaspati ghee, margarine

4. Reason 2: changing oxidation states

Because transition-metal ions can change their oxidation state, they can **take electrons from one reactant and give them to another**, and come back unchanged.

Example: Fe^{3+} catalyses the reaction between iodide and persulphate

$2I^- + S_2O_8^{2-} \rightarrow I_2 + 2SO_4^{2-}$

- Without a catalyst this is **slow**: both reactants are **negative ions**, so they repel each other and rarely collide effectively (high E_a).
- Step 1: $2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$ (Fe^{3+}, positive, attracts I^- and takes an electron from it; yellow Fe^{3+} becomes green Fe^{2+}; brown iodine forms).
- Step 2: $2Fe^{2+} + S_2O_8^{2-} \rightarrow 2Fe^{3+} + 2SO_4^{2-}$ (Fe^{2+}, positive, attracts $S_2O_8^{2-}$ and gives it the electron back).
- Add the two steps: Fe^{3+} cancels out. It is **regenerated**, so it is a catalyst.

Why both steps are feasible: $E°(Fe^{3+}/Fe^{2+})$ = +0.77 V lies between $E°(I_2/I^-)$ = +0.54 V and $E°(S_2O_8^{2-}/SO_4^{2-})$ = +2.01 V. Fe^{3+} can oxidise I^-, and $S_2O_8^{2-}$ can oxidise Fe^{2+}. Fe^{2+} also catalyses the reaction (the same two steps in the other order).

When the catalyst is in the **same phase** as the reactants (here, all in solution), it is called **homogeneous catalysis**.

5. Worked examples

Example 1

Q. Why is iron used as a powder in the Haber process? **A.** Catalysis happens on the surface; a fine powder has a much larger surface area, so more N_2 and H_2 molecules are held and activated at once.

Example 2

Q. Write the two steps by which Fe^{2+} catalyses $2I^- + S_2O_8^{2-} \rightarrow I_2 + 2SO_4^{2-}$. **A.** $2Fe^{2+} + S_2O_8^{2-} \rightarrow 2Fe^{3+} + 2SO_4^{2-}$; then $2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$.

Example 3

Q. Why is Zn^{2+} not a good catalyst for this reaction? **A.** Zinc shows only the +2 oxidation state ($3d^{10}$), so Zn^{2+} cannot take an electron from I^- and give it back; it cannot shuttle electrons.

Example 4

Q. A catalyst lowers E_a from 80 kJ mol^{-1} to 50 kJ mol^{-1}. Does it change ΔH? **A.** No. ΔH depends only on the reactants and products; the catalyst only lowers the energy hill between them.

6. Common mistakes

- ✗ "A catalyst is used up in the reaction." ✓ It takes part in intermediate steps but is regenerated.
- ✗ "A catalyst supplies energy to the reaction." ✓ It provides a path of lower activation energy.
- ✗ "A catalyst shifts the equilibrium towards products." ✓ It speeds up forward and backward reactions equally.
- ✗ "Transition-metal catalysis is only about surfaces." ✓ Ions in solution catalyse by changing oxidation state (Fe^{3+}/Fe^{2+}).

7. Key takeaways

- Transition metals and their compounds are good catalysts because they can adopt multiple oxidation states and form complexes.
- At a surface, reactants bond to metal atoms (3d + 4s electrons): concentration rises, bonds weaken, E_a falls.
- Examples: Fe (Haber), V_2O_5 (Contact), Ni (hydrogenation).
- $Fe^{3+} \rightleftarrows Fe^{2+}$ carries electrons between I^- and $S_2O_8^{2-}$ and is regenerated.

Practice questions

1. (MCQ) The catalyst in the Contact process is: (a) Fe (b) Ni (c) V_2O_5 (d) Pt
2. (MCQ) A catalyst increases the rate by: (a) increasing ΔH (b) lowering E_a (c) shifting equilibrium (d) increasing temperature
3. (MCQ) Nickel is used as a catalyst in: (a) Haber process (b) hydrogenation of oils (c) Contact process (d) Ostwald process
4. (MCQ) For surface bonding, first-row transition metals use: (a) 2p electrons (b) 3d and 4s electrons (c) 4f electrons (d) only 4s electrons
5. (Very short) Name the catalyst used in the Haber process.
6. (Very short) Why is the reaction between I^- and $S_2O_8^{2-}$ slow?
7. (Short) Give two effects of the bonding of reactant molecules to a catalyst surface.
8. (Short) Show with equations how Fe^{3+} catalyses the reaction between iodide and persulphate ions.
9. (Short) Why are transition metals and their compounds good catalysts? (NCERT exercise type)
10. (HOTS) Why can Zn^{2+} not catalyse the iodide–persulphate reaction while Fe^{3+} can?

Answer key

1. (c) V_2O_5.
2. (b) lowering E_a.
3. (b) hydrogenation of oils.
4. (b) 3d and 4s electrons.
5. Finely divided iron.
6. Both are negative ions: they repel each other, so the activation energy is high.
7. The concentration of reactants at the surface increases, and bonds in the reacting molecules weaken (E_a is lowered).
8. $2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$; $2Fe^{2+} + S_2O_8^{2-} \rightarrow 2Fe^{3+} + 2SO_4^{2-}$. Fe^{3+} is regenerated.
9. They can adopt multiple oxidation states (so they can take and give electrons) and form complexes / bonds with reactants at their surface using 3d and 4s electrons, which lowers E_a.
10. Zn shows only +2 ($3d^{10}$), so Zn^{2+} cannot be oxidised or reduced in this reaction; it cannot ferry electrons. Fe switches between +3 and +2.

▶ Watch the video explanation