Iron, Nitrogen and an Electron Ferry: Why Transition Metals Are Good Catalysts

A catalyst speeds up a reaction without being used up by lowering its activation energy. Transition metals are good catalysts because they can adopt multiple oxidation states and form complexes. On a metal surface (iron in the Haber process, V_2O_5 in the Contact process, nickel in hydrogenation) reactant molecules bond to surface atoms using 3d and 4s electrons, so their concentration rises and their bonds weaken. In solution, Fe^{3+} ferries electrons between I^- and $S_2O_8^{2-}$ ($2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$; $2Fe^{2+} + S_2O_8^{2-} \rightarrow 2Fe^{3+} + 2SO_4^{2-}$) and is regenerated.

Name: Date: Score: ____ / 25

A. Fill in the blanks

1. A substance that increases the rate of a reaction without being used up is called a ____.

2. A catalyst works by lowering the ____ energy.

3. In the Haber process the catalyst is finely divided ____.

4. In the Contact process the catalyst is vanadium(V) oxide, ____.

5. First-row transition metals use their 3d and ____ electrons to bond with reactant molecules on a surface.

6. In the iodide–persulphate reaction Fe^{3+} changes to Fe^{2+} and back to Fe^{3+}; it is ____ at the end.

B. True or False

7. A catalyst is used up during the reaction. True / False

8. A catalyst changes the enthalpy change (ΔH) of a reaction. True / False

9. Nickel is used as a catalyst for the hydrogenation of vegetable oils. True / False

10. The reaction between I^- and $S_2O_8^{2-}$ is slow because both reactants are negative ions. True / False

11. Zn^{2+} can catalyse the iodide–persulphate reaction because it shows variable oxidation states. True / False

C. Assertion and reason

12. Assertion (A): Transition metals are good catalysts.
Reason (R): They can adopt multiple oxidation states and form complexes / bonds with reactants.

(a) Both A and R are true, and R explains A
(b) Both A and R are true, but R does not explain A
(c) A is true, R is false
(d) A is false, R is true

Answer: _____

13. Assertion (A): Fe^{3+} catalyses the reaction between I^- and $S_2O_8^{2-}$.
Reason (R): Fe^{3+} can take an electron from I^- and Fe^{2+} can give it to $S_2O_8^{2-}$.

(a) Both A and R are true, and R explains A
(b) Both A and R are true, but R does not explain A
(c) A is true, R is false
(d) A is false, R is true

Answer: _____

D. Choose the correct option

14. Which is the catalyst in the Haber process?

(a) Ni
(b) V_2O_5
(c) Fe
(d) Pt

Answer: _____

15. Bonding of reactants to a catalyst surface:

(a) raises E_a
(b) weakens bonds in the reactants
(c) adds energy
(d) removes the catalyst

Answer: _____

16. Vegetable oil is converted into vanaspati ghee using:

(a) Fe
(b) Ni
(c) V_2O_5
(d) Cu

Answer: _____

17. In $2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$, Fe^{3+} is:

(a) oxidised
(b) reduced
(c) unchanged
(d) a ligand

Answer: _____

18. Which product of the Contact process is used to make sulphuric acid?

(a) SO_2
(b) SO_3
(c) H_2S
(d) S_8

Answer: _____

19. Why is iron used as a fine powder in the Haber process?

(a) to raise ΔH
(b) to increase surface area
(c) to make it heavier
(d) to change the product

Answer: _____

E. Numerical problems

20. Without a catalyst E_a = 85 kJ mol^{-1}; with a catalyst E_a = 55 kJ mol^{-1}. By how much is E_a lowered?

21. Add the steps $2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$ and $2Fe^{2+} + S_2O_8^{2-} \rightarrow 2Fe^{3+} + 2SO_4^{2-}$. What is the overall reaction?

F. Short answer questions

22. Give two effects of the bonding between reactant molecules and the atoms of a catalyst surface.

23. Explain with equations how iron(III) catalyses the reaction between iodide and persulphate ions.

24. Why is Zn^{2+} not a good catalyst for the iodide–persulphate reaction?

G. Match the columns

25. Match each item in Column A with the correct item in Column B.

Column A	Column B	Your answer
1. Haber process	(a) finely divided Fe	1 → ____
2. Contact process	(b) Ni	2 → ____
3. hydrogenation of oils	(c) 3d and 4s electrons	3 → ____
4. $2I^- + S_2O_8^{2-} \rightarrow I_2 + 2SO_4^{2-}$	(d) catalysed by Fe^{3+}	4 → ____
5. surface bonding	(e) V_2O_5	5 → ____

Detailed solutions

1. catalyst

2. activation

3. iron

4. V_2O_5

5. 4s

6. regenerated

7. False. It is regenerated; the same amount is present at the end.

8. False. It only lowers the activation energy.

9. True. Oils become solid fats such as vanaspati ghee.

10. True. They repel each other.

11. False. Zinc shows only +2.

12. (a) NCERT 4.3.12.

13. (a) It is regenerated at the end.

14. (c) Fe. Finely divided iron.

15. (b) weakens bonds in the reactants. It also increases the surface concentration.

16. (b) Ni. Catalytic hydrogenation.

17. (b) reduced. It gains an electron.

18. (b) SO_3. $2SO_2 + O_2 \rightleftharpoons 2SO_3$ on V_2O_5.

19. (b) to increase surface area. More surface, more sites for bonding.

20. 85 − 55. **Answer: 30 kJ mol^{-1}**

21. Fe^{3+} and Fe^{2+} cancel. **Answer: $2I^- + S_2O_8^{2-} \rightarrow I_2 + 2SO_4^{2-}$**

22. The concentration of reactants at the surface increases, and the bonds in the reacting molecules weaken, so the activation energy is lowered (NCERT 4.3.12).

23. $2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$; then $2Fe^{2+} + S_2O_8^{2-} \rightarrow 2Fe^{3+} + 2SO_4^{2-}$. Fe^{3+} is regenerated, so it acts as a catalyst; it lets the two negative ions react via a positive ion.

24. Zinc shows only the +2 oxidation state ($3d^{10}$), so Zn^{2+} cannot take an electron and give it back; it cannot shuttle electrons between the reactants.

25. 1 → (a), 2 → (e), 3 → (b), 4 → (d), 5 → (c).