26.2 Homogeneous and heterogeneous catalysts

Name: _____ Class: _____ Date: _____ **Total: 23 marks**

KEY WORDS catalyst 催化剂 • heterogeneous 多相 • heterogeneous catalyst 多相催化剂 • homogeneous 均相 • homogeneous catalyst 均相催化剂

Objective

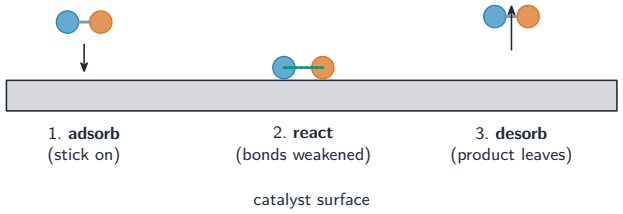
Build the skills to answer exam questions on the **mode of action of catalysts** 催化剂作用方式 — **heterogeneous** 多相 and **homogeneous** 均相 catalysis.

You must be able to:

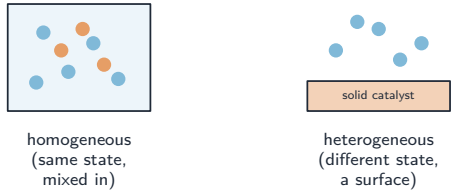
- describe heterogeneous catalysis (adsorption, bond weakening, desorption)
- describe homogeneous catalysis (used in one step, reformed in a later step)
- give the examples in the syllabus

1 Worked examples

Heterogeneous catalysis



A heterogeneous catalyst works at its surface: ***adsorption*** *of reactants →* ***bond weakening*** *→ reaction →* ***desorption*** *of products*



Homogeneous versus heterogeneous catalysis

Examples: **iron** in the Haber process; **Pt/Pd/Rh** in catalytic converters (removing NO_x).

Homogeneous catalysis

A homogeneous catalyst (same state as the reactants) is **used in one step and reformed in a later step**. Examples: oxides of nitrogen catalysing $SO_2 \rightarrow SO_3$ in the atmosphere; Fe^{2+}/Fe^{3+} catalysing the $I^-/S_2O_8^{2-}$ reaction (the Fe ion is regenerated, so it is a catalyst not a reactant).

2 Practice

2.1 State the three stages of heterogeneous catalysis. [3]

2.2 State what "homogeneous" means for a catalyst. [1]

3 Exam-style questions

3.1 In heterogeneous catalysis, the reactant molecules first: [1]

- **A** desorb from the surface
- **B** adsorb onto the catalyst surface
- **C** dissolve in the catalyst
- **D** evaporate

3.2 The iron catalyst in the Haber process is an example of a: [1]

- **A** homogeneous catalyst
- **B** heterogeneous catalyst
- **C** reactant
- **D** product

3.3 Explain how a heterogeneous catalyst speeds up a reaction at its surface. [3]

3.4 Fe^{2+} catalyses the reaction between iodide ions and peroxodisulfate ions. Explain why it is described as a homogeneous catalyst, not a reactant. [2]

3.5 Two industrial reactions use catalysts.

- Reaction 1: $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ over solid iron.
- Reaction 2: $S_2O_8^{2-}(aq) + 2I^-(aq) \rightarrow 2SO_4^{2-}(aq) + I_2(aq)$, catalysed by $Fe^{3+}(aq)$.

(a) Classify each as homogeneous or heterogeneous, giving your reason. [2]

(b) Describe, in three stages, how the iron catalyst speeds up Reaction 1. [3]

(c) Write the two equations that show how Fe^{3+} catalyses Reaction 2, and state what the pair of equations shows about the catalyst. [4]

(d) Explain, with reference to the Boltzmann distribution, why a catalyst increases the rate but not the yield at equilibrium. [3]

Solutions

2.1 adsorption of the reactants onto the surface; reaction (bonds weakened); desorption of the products.

2.2 it is in the same physical state as the reactants.

3.1 B. Reactants first adsorb onto the catalyst surface.

3.2 B. Solid iron with gaseous reactants is a heterogeneous catalyst.

3.3 reactant molecules adsorb onto the catalyst surface; this weakens their bonds and holds them close together, lowering the activation energy; the products then desorb, freeing the surface.

3.4 the Fe^{2+} is used in one step but is regenerated (reformed) in a later step, so it is not used up overall — it is a catalyst, in the same (aqueous) state as the reactants.

3.5 (a) Reaction 1 is **heterogeneous** — the catalyst is a solid and the reactants are gases, so they are in different phases. Reaction 2 is **homogeneous** — catalyst and reactants are all in aqueous solution.
(b) The gases **adsorb** onto the iron surface at active sites, which weakens the strong N ≡ N and H–H bonds; the adsorbed species are held close together in the right orientation, so they react; the ammonia then **desorbs**, freeing the site for more reactant.
(c) $2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$ and $2Fe^{2+} + S_2O_8^{2-} \rightarrow 2Fe^{3+} + 2SO_4^{2-}$. Adding them gives the overall equation with no iron in it — the catalyst is used in the first step and **regenerated** in the second, so it is not consumed. It works because both reactants are negative ions, which repel each other; Fe^{3+} offers a route via oppositely charged species.
(d) The catalyst provides an alternative route of **lower activation energy**; on the Boltzmann distribution a larger fraction of molecules lies to the right of the new, lower E_a, so a greater proportion of collisions is successful; it lowers E_a for the forward and reverse reactions **equally**, so equilibrium is reached sooner but its position — and the yield — is unchanged.