

Exercise walk-through

# 26.2

## Homogeneous and heterogeneous catalysts

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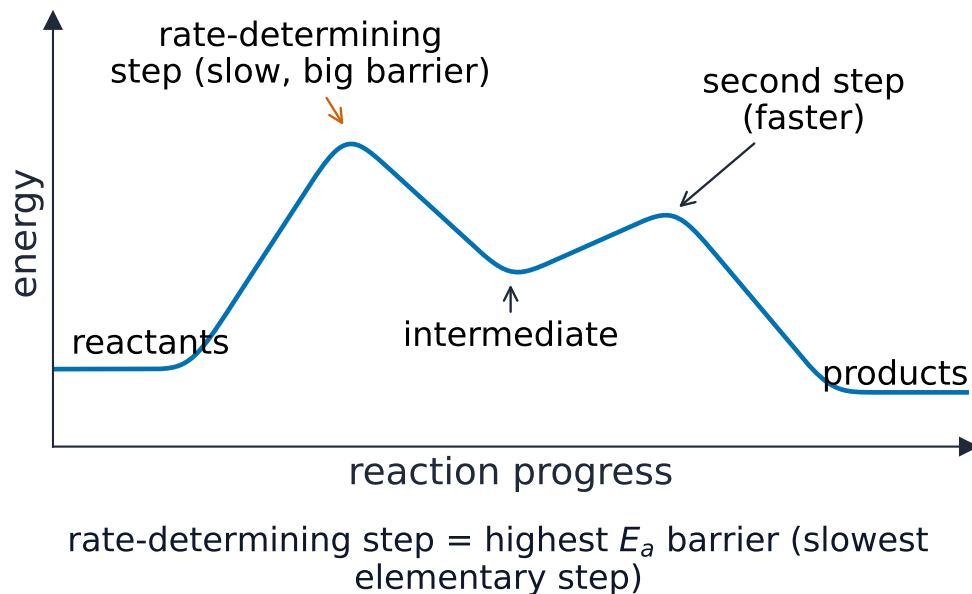
A-Level Chemistry

# Reaction mechanisms

The slowest step is the **rate-determining step** – it controls the overall rate.

Only species up to & including it appear in the rate equation. An **intermediate** is made then used up – not in the overall equation.

# Reaction mechanisms, in detail



The slowest step is the **rate-determining step**  
rate.

– it controls the overall

## Effect of temperature

Raising the temperature increases the rate constant  $k$  (more molecules pass the activation energy), so the rate goes up.

# Catalysts

A **heterogeneous catalyst**

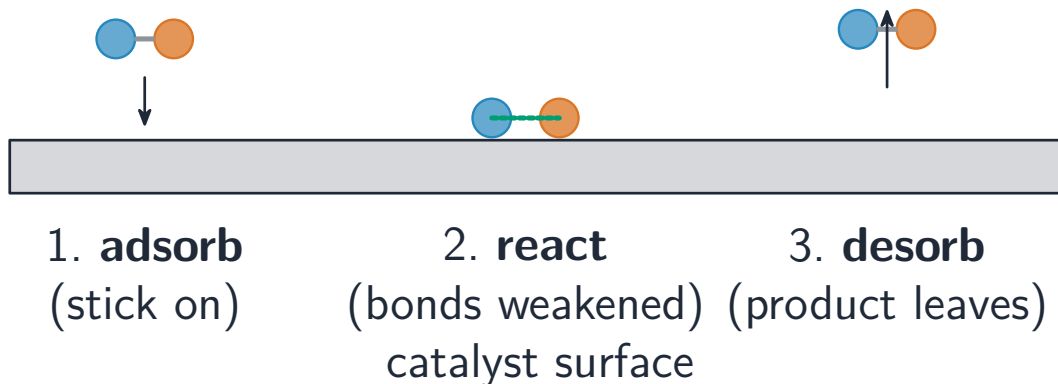
works in three stages:

- **adsorption** onto the surface

- weakened bonds react

- **desorption** of the product

A **homogeneous** one is reformed unchanged.



# The two kinds of catalyst, and the rate vocabulary

## heterogeneous

a **different** physical state from the reactants – iron in the Haber process, and platinum, palladium and rhodium in a catalytic converter

## how it works

reactants adsorb onto the surface, react there, and desorb

## homogeneous catalyst

the **same** physical state as the reactants; it is **used up in one step and remade in a later one**

## order of reaction

the power to which a concentration is raised in the rate equation

## the overall order

the sum of the individual orders

## the initial rate

measured at  $t = 0$ , before any product can interfere – which is why it is used to find orders

Order is found **by experiment**, never from the balanced equation. That is the single most-tested point in this topic.

## Exercises 2.1·2.2

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

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**2.2** State what “homogeneous” means for a catalyst. [1]

## Exercises 2.1·2.2

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

**2.1**

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

**2.2** State what “homogeneous” means for a catalyst. [1]

**2.2**

- it is in the same physical state as the reactants

## Exercises 3.1·3.2

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**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

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**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

## Exercises 3.1-3.2

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**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

**3.1 B**

- Reactants first adsorb onto the catalyst surface

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**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

**3.2 B**

- Solid iron with gaseous reactants is a heterogeneous catalyst

## Exercises 3.3-3.4

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

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

## Exercises 3.3-3.4

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

### 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

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

### 3.4

- the  $\text{Fe}^{2+}$  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

## Exercise 3.5 (a)

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**3.5** Two industrial reactions use catalysts.

- Reaction 1:  $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$  over solid iron.
- Reaction 2:  $\text{S}_2\text{O}_8^{2-}(\text{aq}) + 2\text{I}^-(\text{aq}) \rightarrow 2\text{SO}_4^{2-}(\text{aq}) + \text{I}_2(\text{aq})$ , catalysed by  $\text{Fe}^{3+}(\text{aq})$ .

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

[2]

## Exercise 3.5 (a)

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

(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

## Exercise 3.5 (b)

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

## Exercise 3.5 (b)

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(b)

- The gases **adsorb** onto the iron surface at active sites, which weakens the strong  $\text{N} \equiv \text{N}$  and  $\text{H}-\text{H}$  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

## Exercise 3.5 (c)

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**3.5** Two industrial reactions use catalysts.

- Reaction 1:  $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$  over solid iron.
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(c) Write the two equations that show how  $\text{Fe}^{3+}$  catalyses Reaction 2, and state what the pair of equations shows about the catalyst.

[4]

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

(c)

- $2\text{Fe}^{3+} + 2\text{I}^{-} \rightarrow 2\text{Fe}^{2+} + \text{I}_2$  and  $2\text{Fe}^{2+} + \text{S}_2\text{O}_8^{2-} \rightarrow 2\text{Fe}^{3+} + 2\text{SO}_4^{2-}$ . 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;  $\text{Fe}^{3+}$  offers a route via oppositely charged species

## Exercise 3.5 (d)

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

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

(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