7.1 Chemical equilibria: reversible reactions and dynamic equilibrium

Name: _____ Class: _____ Date: _____ **Total: 11 marks**

KEY WORDS equilibrium • equilibrium constant • dynamic equilibrium • partial pressure • haber

Objective

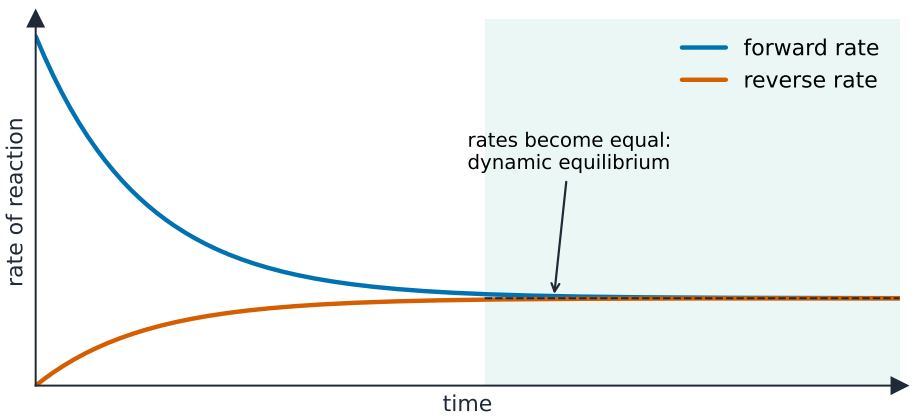
Build the skills to answer exam questions on **chemical equilibria – dynamic equilibrium**, **Le Chatelier's principle**, the equilibrium constants K_c and K_p, and the **Haber** process.

You must be able to:

- explain dynamic equilibrium and use Le Chatelier's principle
- write K_c and K_p expressions and use partial pressures
- carry out equilibrium calculations and explain the Haber/Contact conditions

1 Key knowledge and worked examples

Dynamic equilibrium and Le Chatelier



at equilibrium: $\text{rate}_f = \text{rate}_r$ · $K_c = \frac{[\text{products}]}{[\text{reactants}]}$ (stoich. powers)

At dynamic equilibrium the forward and reverse rates are equal, so concentrations stay constant (closed system)

the equilibrium shifts to *oppose* the change you make

increase [reactant]	→	towards the **products**
increase pressure	→	to the **fewer-gas-molecules** side
increase temperature	→	in the **endothermic** direction

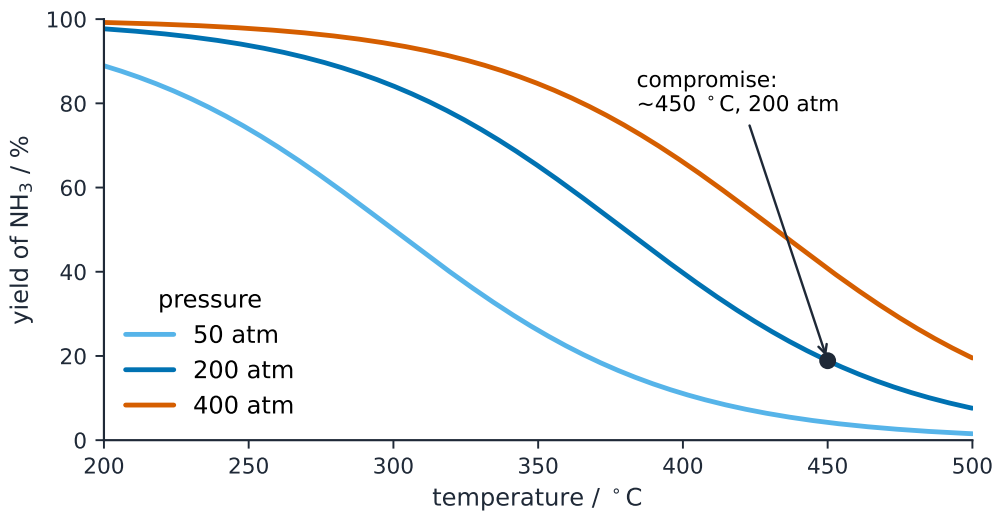
a **catalyst** speeds both directions equally, so it gives *no shift*

Le Chatelier: the equilibrium shifts to oppose a change. ↑[reactant]→products; ↑pressure→fewer gas molecules; ↑temperature→endothermic direction; catalyst→no shift

Equilibrium constants

For $aA + bB \rightleftharpoons cC + dD$: $K_c = \frac{[C]^c[D]^d}{[A]^a[B]^b}$. **Example.** $H_2 + I_2 \rightleftharpoons 2HI$ with $[H_2]=[I_2]=0.20$, $[HI]=1.6$: $K_c = \frac{1.6^2}{0.20 \times 0.20} = 64$ (no units). Partial pressure = mole fraction × total pressure → K_p. **Only temperature changes K.**

The Haber process



exothermic: lower T ↑ yield · higher P ↑ yield

Haber ($N_2 + 3H_2 \rightleftharpoons 2NH_3$, exothermic): more NH_3 at low T, high p; ~450 °C, 200 atm, Fe catalyst is the compromise

2 Practice

2.1 State the **two** features of a system at dynamic equilibrium. [2]

2.2 Write the K_c expression for $N_2 + 3H_2 \rightleftharpoons 2NH_3$. [1]

3 Exam-style questions

3.1 For an **exothermic** equilibrium, increasing the temperature: [1]

- ☐ **A** shifts it towards the products
- **B** shifts it towards the reactants (the endothermic direction)
- **C** has no effect
- **D** increases the value of K_c towards products

3.2 Adding a catalyst to a system at equilibrium: [1]

- ☐ **A** shifts it towards the products
- **B** shifts it towards the reactants
- **C** does not change the position of equilibrium
- **D** increases K_c

3.3 At equilibrium, $N_2O_4 \rightleftharpoons 2NO_2$ has $[N_2O_4] = 0.10$ and $[NO_2] = 0.20$ mol dm^{-3}.

(a) Write the expression for K_c and calculate its value (give units). [3]

(b) State the effect on the **value** of K_c of increasing the pressure. [1]

3.4 A gas mixture contains 3.0 mol of SO_2 and 1.0 mol of O_2 at a total pressure of 400 kPa. Calculate the partial pressure of SO_2. [2]

Solutions

Each answer shows the steps, then the **result**.

2.1

- the forward and reverse rates are equal; the concentrations of reactants and products stay constant

2.2

- $K_c = \dfrac{[NH_3]^2}{[N_2][H_2]^3}$

3.1 B

- Raising T shifts an exothermic equilibrium towards the reactants (endothermic direction)

3.2 C

- A catalyst speeds both directions equally – no shift

3.3

(a)

- $K_c = \dfrac{[NO_2]^2}{[N_2O_4]} = \dfrac{0.20^2}{0.10} = 0.40 \text{ mol dm}^{-3}$

(b)

- no change – only temperature changes K_c

3.4

- total moles = 4.0; mole fraction of SO_2 = 3.0/4.0 = 0.75; $p(SO_2) = 0.75 \times 400 =$ 300 kPa