

7.1 Chemical equilibria: reversible reactions and dynamic equilibrium

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

KEY WORDS equilibrium 平衡 • equilibrium constant 平衡常数 • dynamic equilibrium 动态平衡
• partial pressure 分压 • haber 哈伯法

Objective

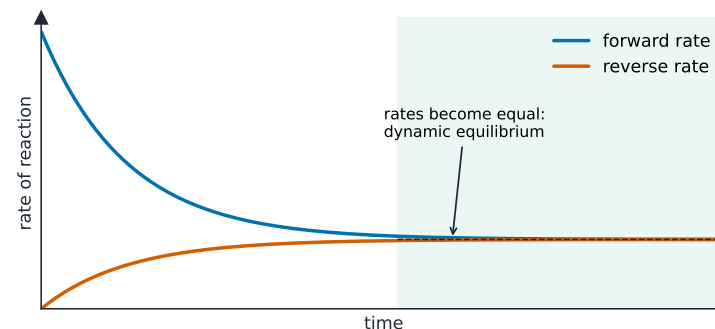
Build the skills to answer exam questions on **chemical equilibria** — **dynamic equilibrium** 动态平衡, **Le Chatelier's principle** 勒夏特列原理, the equilibrium constants K_c and K_p , and the **Haber** 哈伯法 process.

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 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

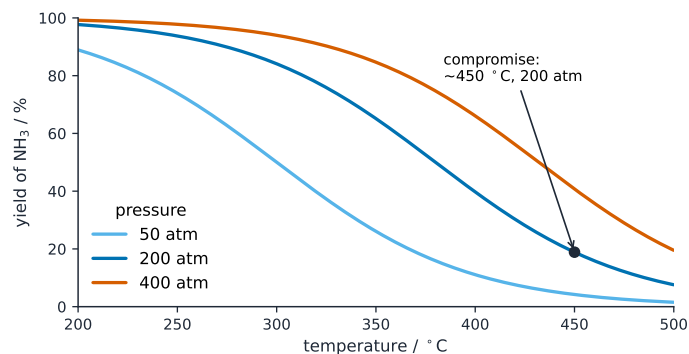
a **catalyst** speeds both directions equally, so it gives **no shift**

Le Chatelier: the equilibrium shifts to oppose a change. $\uparrow[\text{reactant}] \rightarrow \text{products}$; $\uparrow \text{pressure} \rightarrow \text{fewer gas molecules}$; $\uparrow \text{temperature} \rightarrow \text{endothermic direction}$; catalyst $\rightarrow$ 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 $\times$ total pressure $\rightarrow K_p$. **Only temperature changes K .**

■ The Haber process



exothermic: lower $T \uparrow$ yield · higher $P \uparrow$ yield

Haber ($\text{N}_2 + 3\text{H}_2 \rightleftharpoons 2\text{NH}_3$, 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 $\text{N}_2 + 3\text{H}_2 \rightleftharpoons 2\text{NH}_3$. [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, $\text{N}_2\text{O}_4 \rightleftharpoons 2\text{NO}_2$ has $[\text{N}_2\text{O}_4] = 0.10$ and $[\text{NO}_2] = 0.20 \text{ mol dm}^{-3}$.

(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

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

$$\mathbf{2.2} \quad K_c = \frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]^3}.$$

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.

$$\mathbf{3.3} \text{ (a) } K_c = \frac{[\text{NO}_2]^2}{[\text{N}_2\text{O}_4]} = \frac{0.20^2}{0.10} = 0.40 \text{ mol dm}^{-3}.$$

(b) no change — only temperature changes K_c .

3.4 total moles = 4.0; mole fraction of $\text{SO}_2 = 3.0/4.0 = 0.75$; $p(\text{SO}_2) = 0.75 \times 400 = 300 \text{ kPa}$.