Exercise walk-through

Chemical equilibria: reversible reactions, dynamic equilibrium ▪ 7.1

eXercise

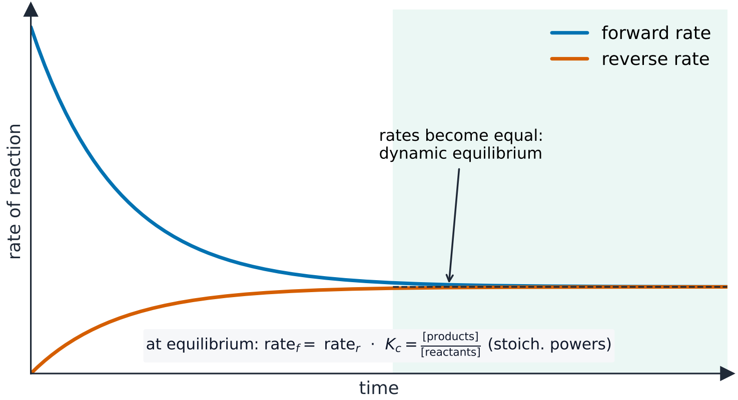
You must be able to

- 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

Method — Dynamic equilibrium and Le Chatelier

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

Method — Dynamic equilibrium and Le Chatelier



A graph: the forward rate falls and the reverse rate rises until they meet and stay equal

Method — Dynamic equilibrium and Le Chatelier

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*

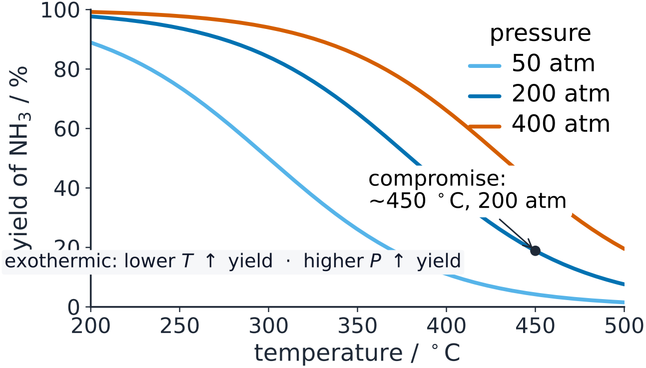
Three changes with arrows showing the equilibrium shift

Method — Equilibrium constants

For $a\mathrm{A} + b\mathrm{B} \rightleftharpoons c\mathrm{C} + d\mathrm{D}$: $K_c = \dfrac{[\mathrm{C}]^c[\mathrm{D}]^d}{[\mathrm{A}]^a[\mathrm{B}]^b}$. **Example.** $\mathrm{H}_2 + \mathrm{I}_2 \rightleftharpoons 2\mathrm{HI}$ with [H]=[I]=0.20, [HI]=1.6: $K_c = \dfrac{1.6^2}{0.20 \times 0.20} = 64$ (no units). Partial pressure = mole fraction × total pressure → K_p. **Only temperature changes K.**

Method — The Haber process

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



A graph of ammonia yield vs temperature for three pressures

Practice 2.1 ▪ 2 marks

State the **two** features of a system at dynamic equilibrium.

Solution 2.1

Method: Dynamic equilibrium and Le Chatelier

Worked steps

the forward and reverse rates are equal **B1**; the concentrations of reactants and products stay constant **B1**.

Practice 2.2 ▪ 1 mark

Write the K_c expression for $N_2 + 3H_2 \rightleftharpoons 2NH_3$.

Solution 2.2

Worked steps

$$K_c = \frac{[\mathrm{NH_3}]^2}{[\mathrm{N_2}][\mathrm{H_2}]^3}\ \boxed{\textbf{B1}}.$$

Exam-style 3.1 ▪ 1 mark

For an **exothermic** equilibrium, increasing the temperature:

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

Solution 3.1

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

Worked steps

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

Exam-style 3.2 ▪ 1 mark

Adding a catalyst to a system at equilibrium:

A shifts it towards the products

B shifts it towards the reactants

C does not change the position of equilibrium

D increases K_c

Solution 3.2

Method: Dynamic equilibrium and Le Chatelier

A shifts it towards the products

B shifts it towards the reactants

C does not change the position of equilibrium ✓

D increases K_c

Worked steps

C. A catalyst speeds both directions equally — no shift.

Exam-style 3.3 ▪ 3 marks

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).

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

Solution 3.3

Method: Equilibrium constants

Worked steps

(a) $K_c = \dfrac{[NO_2]^2}{[N_2O_4]} = \dfrac{0.20^2}{0.10}$ **M1** $= 0.40$ **A1** mol dm^{-3} **A1**.

(b) no change — only temperature changes K_c **B1**.

Exam-style 3.4 ▪ 2 marks

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.

Solution 3.4

Method: Equilibrium constants

Worked steps

total moles $= 4.0$; mole fraction of SO $= 3.0/4.0 = 0.75$ **M1**; $p(\mathrm{SO_2}) = 0.75 \times 400 = 300$ kPa **A1**.