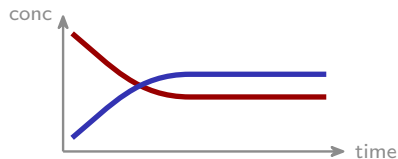
Equilibrium

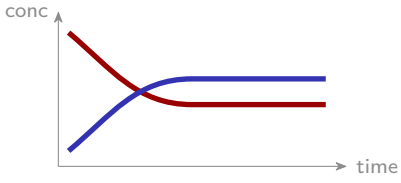
AP Chemistry ▪ Unit 7

AP Chemistry



What we will cover

1. Dynamic equilibrium
2. The reaction quotient and K
3. ICE tables
4. Magnitude and properties of K
5. Le Chatelier's principle
6. Solubility equilibria

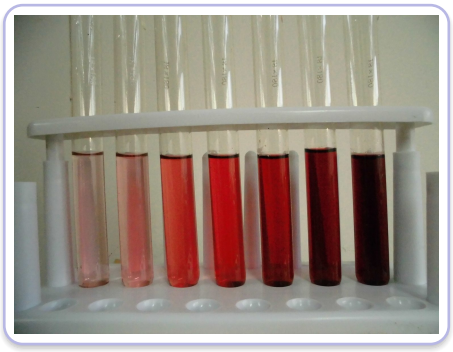


1 Dynamic

Dynamic equilibrium

Chemical equilibrium 化学平衡 is **dynamic** 动态的: the forward and reverse reactions run at the same rate, so concentrations stay constant (not zero).

> Reached from either side – all reactant or all product gives the same mixture.



Dynamic equilibrium: forward and reverse still run

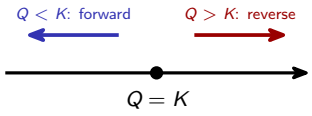
2 Q and K

The reaction quotient and K

Equilibrium constant

$$K = \frac{[\mathrm{C}]^c[\mathrm{D}]^d}{[\mathrm{A}]^a[\mathrm{B}]^b}$$

Reaction quotient 反应商 Q has the same form at any moment. Leave out pure solids and liquids.



Q vs K predicts the direction every time.

3 ICE

ICE tables

Organise the work in an **ICE table** ICE 表: **I**nitial, **C**hange ($\pm x$ by coefficient), **E**quilibrium.

Then substitute into K

When K is tiny, assume $x \ll$ initial (avoid the quadratic) – and check.

	HA	H^+	A^-
I	0.10	0	0
C	$-x$	$+x$	$+x$
E	$0.10-x$	x	x

$$K = \frac{x^2}{0.10 - x} \approx \frac{x^2}{0.10}.$$

Worked example – an ICE table

For $H_2 + I_2 \rightleftharpoons 2HI$ with $K_c = 50$, starting from 0.100 M of each reactant, find the equilibrium concentrations.

- I: 0.100, 0.100, 0. C: $-x$, $-x$, $+2x$. E: $0.100 - x$, $0.100 - x$, $2x$
- $K_c = \dfrac{(2x)^2}{(0.100 - x)^2} = 50$
- take the square root of both sides: $\dfrac{2x}{0.100 - x} = \sqrt{50} = 7.07$
- $x = 0.0779$, so $[HI] = 0.156$ M and each reactant is 0.022 M

The perfect square lets you take a root instead of solving a quadratic. Always check whether the expression is one before reaching for the formula.

4 Magnitude

Magnitude and properties of K

The size of K shows where the balance sits:

- $K \gg 1$ – product-favored
- $K \ll 1$ – reactant-favored
- $K \approx 1$ – comparable amounts

Manipulating K

- reverse: $K \to 1/K$
- scale by n: $K \to K^n$
- add reactions: $K \to K_1 K_2$

Writing K, and manipulating it

writing K	from the balanced equation – and pure solids and liquids are left out
K_c and K_p	from equilibrium concentrations, or from partial pressures
$K \gg 1$	products strongly favoured – the reaction is nearly complete
$K \ll 1$	reactants favoured – very little product forms
reversing the reaction	inverts K, giving $1/K$
multiplying coefficients by n	raises K to the nth power; adding two reactions multiplies their Ks

Leaving out solids and liquids is not a simplification – their concentration does not change, so it is already absorbed into K.

5 Le Chatelier

Le Chatelier's principle

Le Chatelier 勒夏特列原理: a disturbed system shifts to partly undo the change.

- add a substance ⇒ shift *away* from it
- raise pressure ⇒ toward fewer gas moles
- add heat ⇒ shift as if heat were added

Industry shifts equilibrium with Le Chatelier

Justifying every Le Chatelier shift with Q

Q	the reaction quotient – the same expression as K, evaluated at any moment
$Q < K$	too few products, so the reaction shifts right
$Q > K$	too many products, so it shifts left
$Q = K$	at equilibrium; no net change
the method	a disturbance changes Q, and the system reacts to bring Q back to K
why it is better	this makes the reasoning quantitative rather than a memorised rule about stress

Only temperature changes K itself. Everything else changes Q, which is why every other disturbance can be reasoned about this way.

6 Solubility

Solubility equilibria

A sparingly soluble salt has a **solubility product** 溶度积 K_{sp} (solid left out):

AgCl $\rightleftharpoons \mathrm{Ag^+ + Cl^-}$

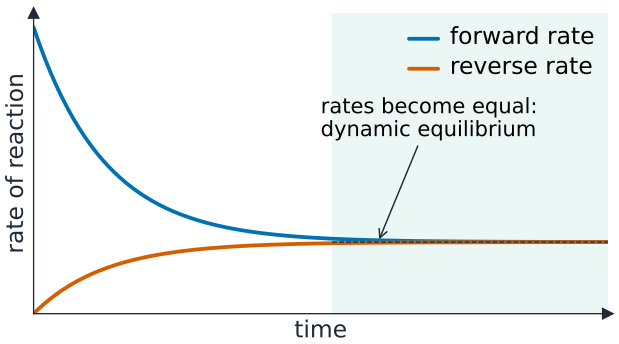
$$K_{sp} = [\mathrm{Ag^+}][\mathrm{Cl^-}] = s^2$$

$s = \sqrt{1.8 \times 10^{-10}} = 1.3 \times 10^{-5}\,\mathrm{M}.$

Common-ion effect 同离子效应: adding a shared ion shifts dissolving backward – less dissolves (K_{sp} unchanged).

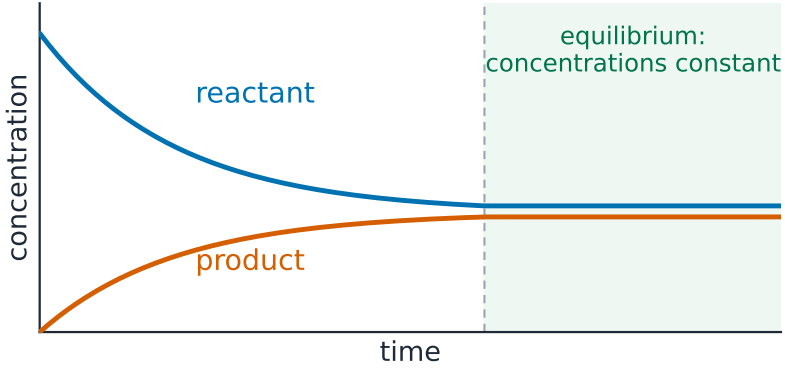
In $0.10\,\mathrm{M}$ NaCl, AgCl solubility drops to $1.8 \times 10^{-9}\,\mathrm{M}$.

Introduction to Equilibrium



Dynamic equilibrium: the forward and reverse rates become equal

Reactant and product concentrations change



at equilibrium: $r_f = r_r \cdot K_c = \frac{[\text{products}]}{[\text{reactants}]}$

Reactant and product concentrations change, then hold constant once equilibrium is reached

Direction of Reversible Reactions

At equilibrium the amounts of reactants and products are fixed but usually **not** equal.

> Whether the mixture favors products or reactants depends on the reaction; you compare the current state to the equilibrium condition to predict which way it shifts.

Introduction to Le Chatelier's Principle

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's principle: the equilibrium shifts to oppose the change made

Exam tips

- At equilibrium the forward and reverse **rates** are equal, but the **amounts** are usually not.
- Leave pure solids and liquids out of the K expression; a large K favours products, a small K favours reactants.
- Apply **Le Chatelier**: add reactant $\rightarrow$ shift forward; raise pressure $\rightarrow$ shift toward fewer gas moles; raise temperature $\rightarrow$ shift in the **endothermic** direction.
- A **catalyst does not shift** the position of equilibrium – it only speeds the approach.
- Use an **ICE table** for equilibrium concentrations, and the small-x approximation when K is small.

7 Recap

Unit 7 – key takeaways

1 Equilibrium

dynamic; equal forward and reverse rates

2 Q vs K

$Q < K$ forward, $Q > K$ reverse; ICE table for K

3 Le Chatelier

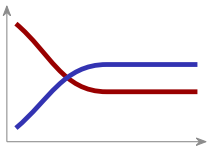
shift to undo a stress; only T changes K

4 Solubility

K_{sp}; common ion suppresses dissolving

Check yourself

1. At equilibrium, how do the forward and reverse rates compare?
2. If $Q < K$, which way does the reaction run?
3. Which stress actually changes the value of K?
4. Does adding a common ion raise or lower solubility?



Answers **1.** they are equal **2.** forward **3.** temperature **4.** lower