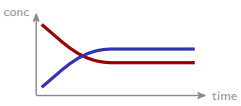
Equilibrium

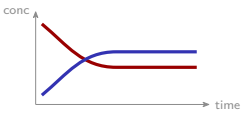
AP Chemistry ▪ Unit 7

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

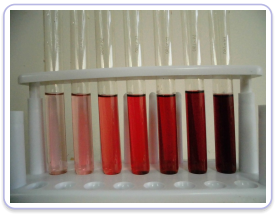


1 Dynamic

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

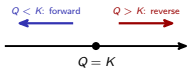
2 Q and K

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

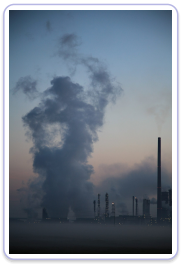
Leaving out solids and liquids is not a simplification – their concentration does not change, so it is already absorbed into K.

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

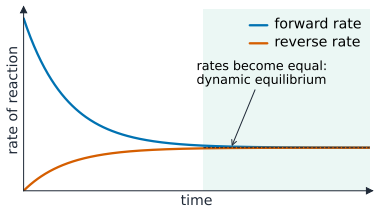
$$K_{sp} = [\mathrm{Ag^+}][\mathrm{Cl^-}] = s^2$$

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

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

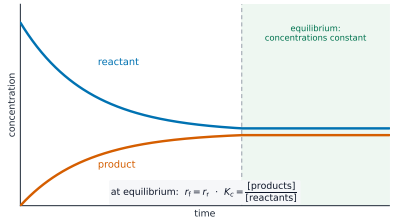
In $0.10\,\mathrm{M}$ NaCl, AgCl solubility drops to $1.8 \times 10^{-9}\,\mathrm{M}$.

Introduction to Equilibrium



Dynamic equilibrium: the forward and reverse rates become equal

Reactant and product concentrations change



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 → shift forward; raise pressure → shift toward fewer gas moles; raise temperature → 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

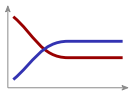
2 Q vs K
$Q < K$ forward, $Q > K$ reverse; ICE table for K

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