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Topic 17
Equilibrium HL

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Calculating equilibrium concentrations from K_c and initial concentrations

Equilibrium law

The K_c for the following reaction is 6.78 at a certain temperature.

The initial concentrations of NO and SO_3 were both 0.0300 mol dm^{-3}

Calculate the equilibrium concentration of each reactant.

$$SO_{3(g)} + NO_{(g)} \rightleftharpoons NO_{2(g)} + SO_{2(g)}$$

	$SO_{3(g)}$	$NO_{(g)}$	$NO_{2(g)}$	$SO_{2(g)}$
Initial (mol dm^{-3})	0.0300	0.0300	0.00	0.00
Change (mol dm^{-3})	$-x$	$-x$	$+x$	$+x$
Equilibrium (mol dm^{-3})	$0.0300 - x$	$0.0300 - x$	x	x

Equilibrium law

$$K_c = \frac{[NO_2][SO_2]}{[SO_3][NO]} = \frac{x^2}{(0.0300-x)^2} = 6.78$$

Take the square root of both sides of the equation

$$2.60 = \frac{x}{0.0300-x}$$

$$x = \frac{0.078}{3.60} = 0.0217$$

Equilibrium law

$[SO_3] = 0.0300 - 0.0217 = 0.00830\ moldm^{-3}$

$[NO] = 0.0300 - 0.0217 = 0.00830\ moldm^{-3}$

$[NO_2] = 0.0217\ moldm^{-3}$

$[SO_2] = 0.0217\ moldm^{-3}$

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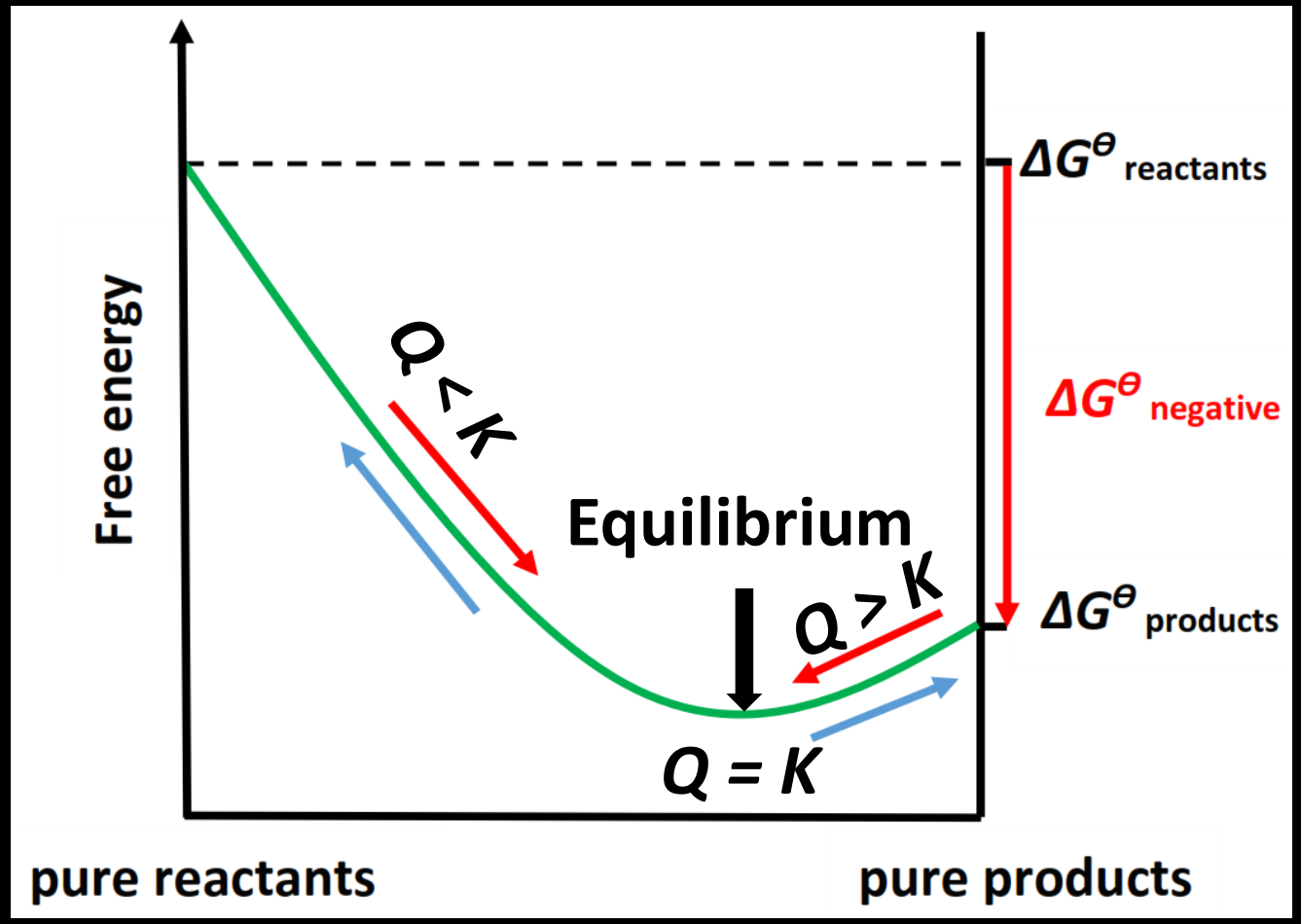
Gibbs free energy and equilibrium

Gibbs free energy and equilibrium



At the minimum value of Gibbs free energy, the reaction is at equilibrium.

The position of equilibrium corresponds to the maximum value of entropy.

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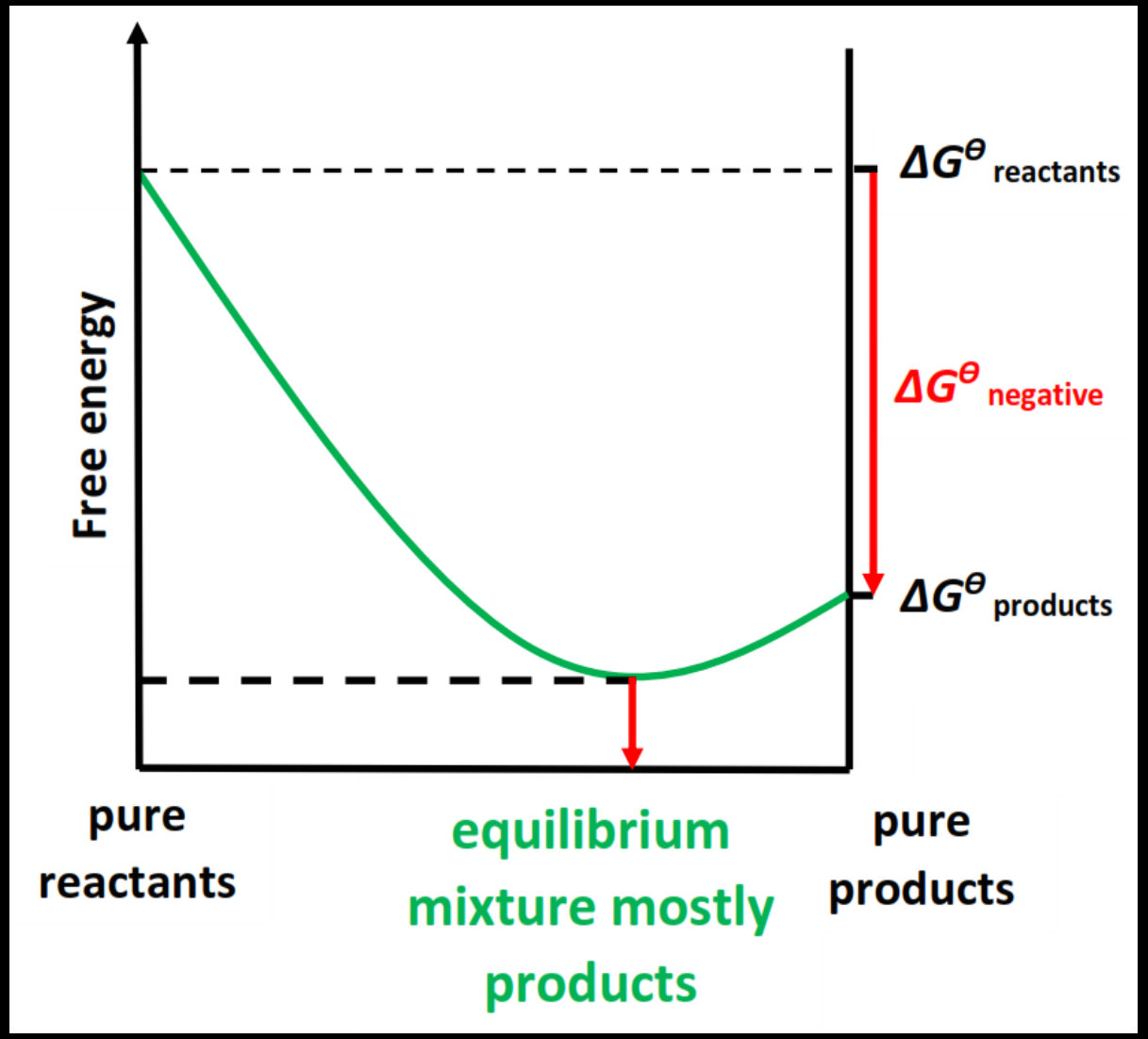
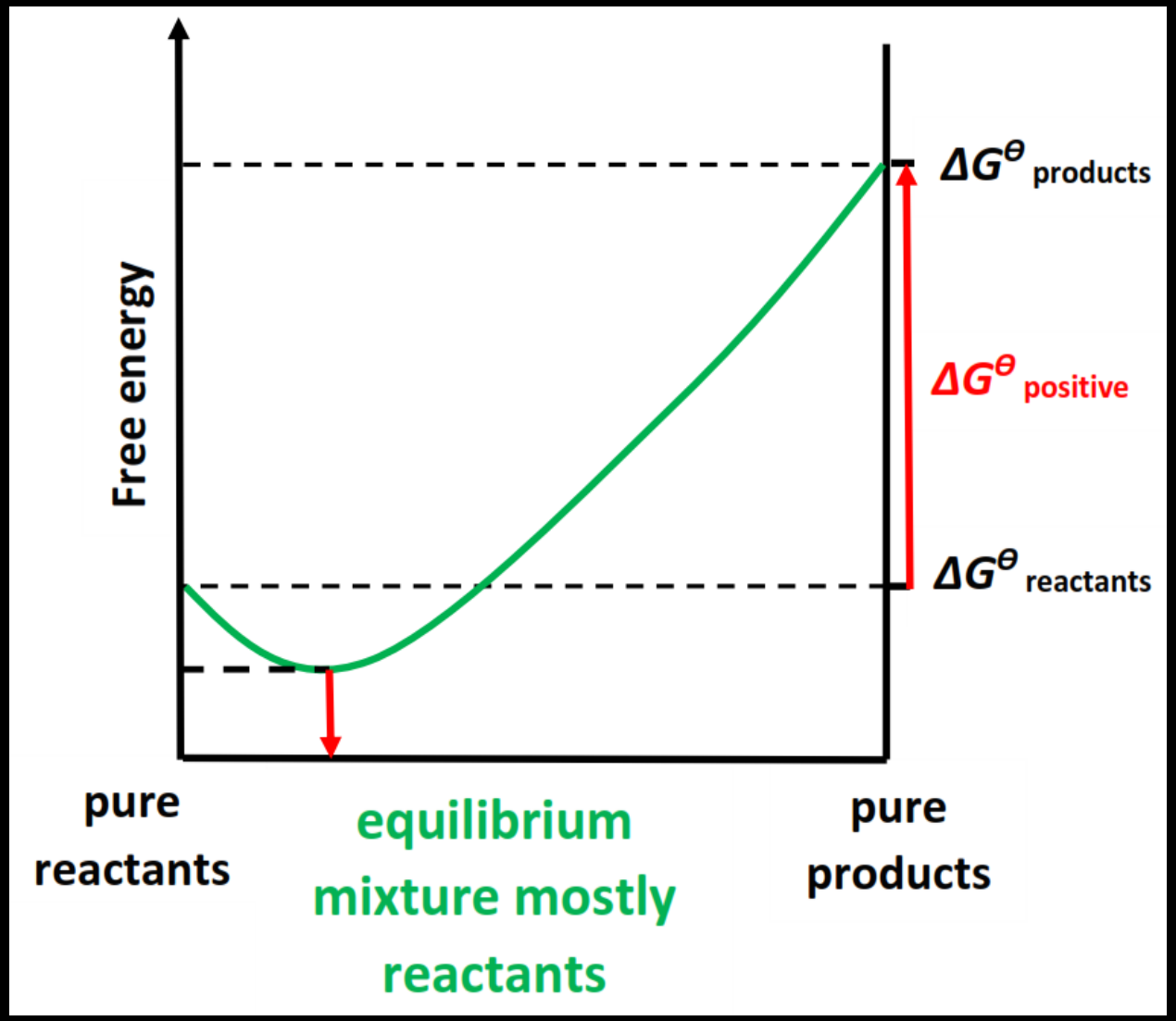
Gibbs free energy and equilibrium

Spontaneous reaction



Non- spontaneous reaction



Gibbs free energy and equilibrium

$$\Delta G^{\ominus} = -RT \ln K$$

$\Delta G^{\ominus}$ – standard Gibbs free energy change

R – universal gas constant (8.31 J K^{-1} mol^{-1})

T – temperature in kelvin (K)

ln *K* – natural log of *K*

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Gibbs free energy and equilibrium

$$\Delta G^{\ominus} = -RT \ln K$$

$$\ln K = -\frac{\Delta G^{\ominus}}{RT}$$

$$K = e^{-\frac{\Delta G^{\ominus}}{RT}}$$

Gibbs free energy and equilibrium

$$\Delta G^{\ominus} = -RT \ln K$$

Calculate the value of $\Delta G^{\ominus}$ at 298 K for the following reaction, given that the equilibrium constant, K, has a value of 5.8×10^5

$$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$$

Gibbs free energy and equilibrium

$$\Delta G^{\ominus} = -RT \ln K$$

Calculate the value of $\Delta G^{\ominus}$ at 298 K for the following reaction, given that the equilibrium constant, K, has a value of 5.8×10^5

$$\Delta G^{\ominus} = -8.31 \times 298 \times \ln 5.8 \times 10^5$$

$$\Delta G^{\ominus} = -32864 \text{ J mol}^{-1}$$

$$\Delta G^{\ominus} = -32.9 \text{ kJ mol}^{-1}$$

Gibbs free energy and equilibrium

Standard Gibbs free energy change ($\Delta G^{\ominus}$)	Equilibrium constant (K)	Equilibrium mixture
$\Delta G^{\ominus} < 0$ (negative)	$K > 1$	Equilibrium lies to the right - products favoured
$\Delta G^{\ominus} > 0$ (positive)	$K < 1$	Equilibrium lies to the left - reactants favoured
$\Delta G^{\ominus} = 0$	$K = 1$	neither reactants nor products favoured

Gibbs free energy and equilibrium

Reactions that have a more negative ΔG value have a larger K_c and vice versa.

Reaction (298 K)	$\Delta G^{\ominus}$ (kJ mol^{-1})	K_c
$2SO_{3(g)} \rightleftharpoons 2SO_{2(g)} + O_{2(g)}$	+141.7	1.4×10^{-25}
$H_2O_{(l)} \rightleftharpoons H^+_{(aq)} + OH^-_{(aq)}$	+79.9	1.0×10^{-14}
$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$	-32.9	5.8×10^{5}
$Zn_{(s)} + Cu^{2+}_{(aq)} \rightarrow Zn^{2+}_{(aq)} + Cu_{(s)}$	-211	1.4×10^{37}

Gibbs free energy and equilibrium

If the value of $K = 1$, then $\Delta G^{\ominus}$ = zero.

$$\Delta G^{\ominus} = -RT \ln K$$

$$\Delta G^{\ominus} = -RT \ln 1$$

$$\Delta G^{\ominus} = 0$$

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Gibbs free energy and equilibrium

$$\Delta G^{\ominus} = -RT \ln K$$

$$\Delta G = \Delta G^{\ominus} + RT \ln Q$$

$$\Delta G = -RT \ln K + RT \ln Q$$

$$\Delta G = RT \ln \frac{Q}{K}$$

Gibbs free energy and equilibrium

$$\Delta G = RT \ln \frac{Q}{K}$$

Q/K	$\ln Q/K$	ΔG
<1	<0	negative – reaction will proceed to right
>1	>0	positive – reaction will proceed to left
1	0	zero – reaction is at equilibrium

Gibbs free energy and equilibrium

At equilibrium, $Q = K$, therefore $Q/K = 1$

$$\Delta G = RT \ln \frac{Q}{K}$$

$$\Delta G = RT \ln 1$$

$$\Delta G = 0$$

At equilibrium, ΔG is zero.

Gibbs free energy and equilibrium

A reaction at equilibrium has the minimum value of Gibbs free energy and a maximum value of entropy.

The $\Delta G^{\ominus}$ for a reaction can be calculated from the equilibrium constant, K, and vice versa.

The $\Delta G^{\ominus}$ also gives us information about the position of equilibrium for a reaction.

At equilibrium, ΔG for a reaction is zero.