Section 20.3
Free Energy, the Reaction Quotient and the Equilibrium Constant

Bill Vining
SUNY College at Oneonta

Recall Q, K and Reaction Favorability

$$a\,A + b\,B \rightleftarrows c\,C + d\,D \qquad Q = \frac{[C]^c[D]^d}{[A]^a[B]^b}$$

Q < K — The system is not at equilibrium. Reactants will be consumed, and product concentration will increase until $Q = K$. The reaction will proceed in the forward direction as written (reactants → products).

Q = K — The system is at equilibrium, and no further change in reactant or product concentration will occur.

Q > K — The system is not at equilibrium. Products will be consumed, and reactant concentration will increase until $Q = K$. The reaction proceeds to the left as written (reactants ← products).

ΔG, ΔG^o and Q

Q represents the current state of the system.

ΔG determines if the reaction system in its current state is spontaneous in either direction.

ΔG^o determines if the system is product-favored or reactant-favored.

$\Delta G < 0$ Reaction is spontaneous in the forward direction (reactants $\rightarrow$ products).

$\Delta G = 0$ Reaction is at equilibrium.

$\Delta G > 0$ Reaction is spontaneous in the reverse direction (reactants $\leftarrow$ products).

$\Delta G^o < 0$ Reaction is product-favored.
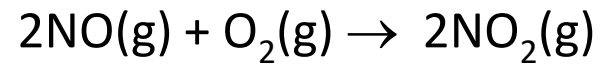
$\Delta G^o = 0$ Reaction is neither reactant- or product-favored..

$\Delta G^o > 0$ Reaction is reactant-favored.

Connecting ΔG, ΔG^o and Q

$\Delta G = \Delta G^o + RT \ln Q$

Use standard thermodynamic data *(linked)* to calculate ΔG at 298.15 K for the following reaction, assuming that all gases have a pressure of 16.91 mm Hg.
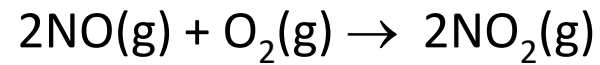
$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

	ΔG_f^o (kJ/mol)
NO(g)	86.6
O_2(g)	0
NO_2(g)	51.3

Connecting ΔG, ΔG° and Q

$$\Delta G = \Delta G^o + RT \ln Q$$

Use standard thermodynamic data *(linked)* to calculate ΔG at 298.15 K for the following reaction, assuming that all gases have a pressure of 16.91 mm Hg.

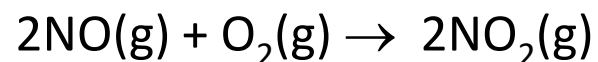$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

	ΔG_f^o (kJ/mol)
$NO(g)$	86.6
$O_2(g)$	0
$NO_2(g)$	51.3

ΔG, ΔG^o and the Equilibrium Constant, K

At equilibrion, $\Delta G = 0$ so $0 = \Delta G^o + RT \ln Q$

$\Delta G^o = -RT \ln Q$ and $\ln K = -\dfrac{\Delta G^o}{RT}$ $K = e^{-\frac{\Delta G^o}{RT}}$

Use standard thermodynamic data to calculate K at 298.15 K for the following reaction.

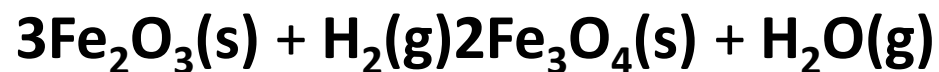$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

	ΔG_f^o (kJ/mol)
NO(g)	86.6
O_2(g)	0
NO_2(g)	51.3

ΔG^o = -70.6 kJ

ΔG, ΔG^o and the Equilibrium Constant, K

A student determines the value of the equilibrium constant to be **1.11E6** for the following reaction.

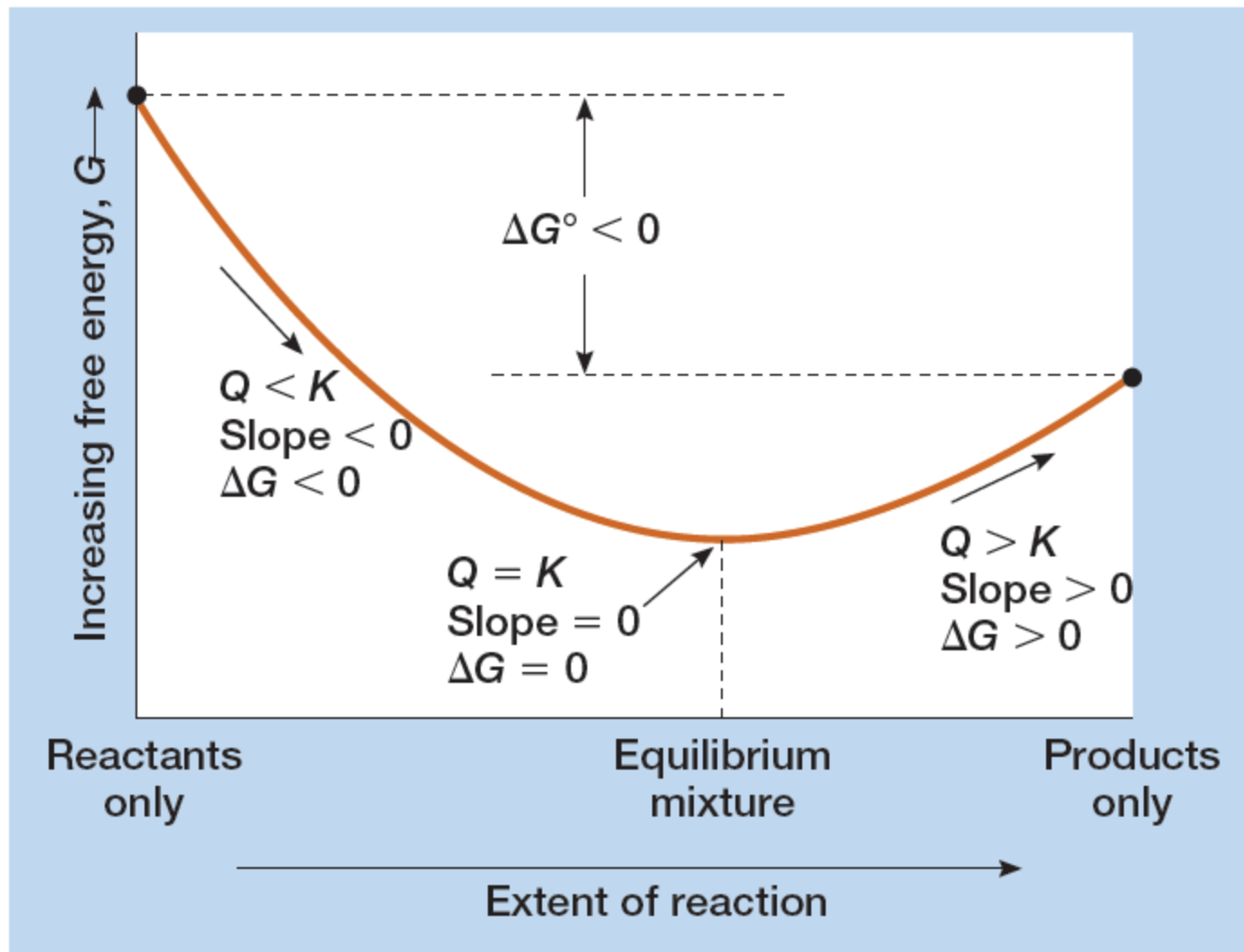**3Fe$_2$O$_3$(s) + H$_2$(g)2Fe$_3$O$_4$(s) + H$_2$O(g)**

$$\ln K = -\frac{\Delta G^o}{RT} \qquad K = e^{-\frac{\Delta G^o}{RT}}$$

Based on this value of K$_{eq}$: ΔG° for this reaction is expected to be (greater, less) than zero.

Calculate ΔG° and the free energy change for the reaction of **1.67** moles of **Fe$_2$O$_3$(s)** at standard conditions at 298K.

$\Delta G, \Delta G^o, Q, \text{and } K$

Reaction is product-favored at equilibrium
$\Delta G°$ is negative, $K > 1$

Increasing free energy, $G \longrightarrow$

$\Delta G° < 0$

$Q < K$
Slope < 0
$\Delta G < 0$

$Q = K$
Slope $= 0$
$\Delta G = 0$

$Q > K$
Slope > 0
$\Delta G > 0$

Reactants only

Equilibrium mixture

Products only

Extent of reaction

∆G, ∆Gº, Q, and K

Reaction is reactant-favored at equilibrium
∆G° is positive, K < 1
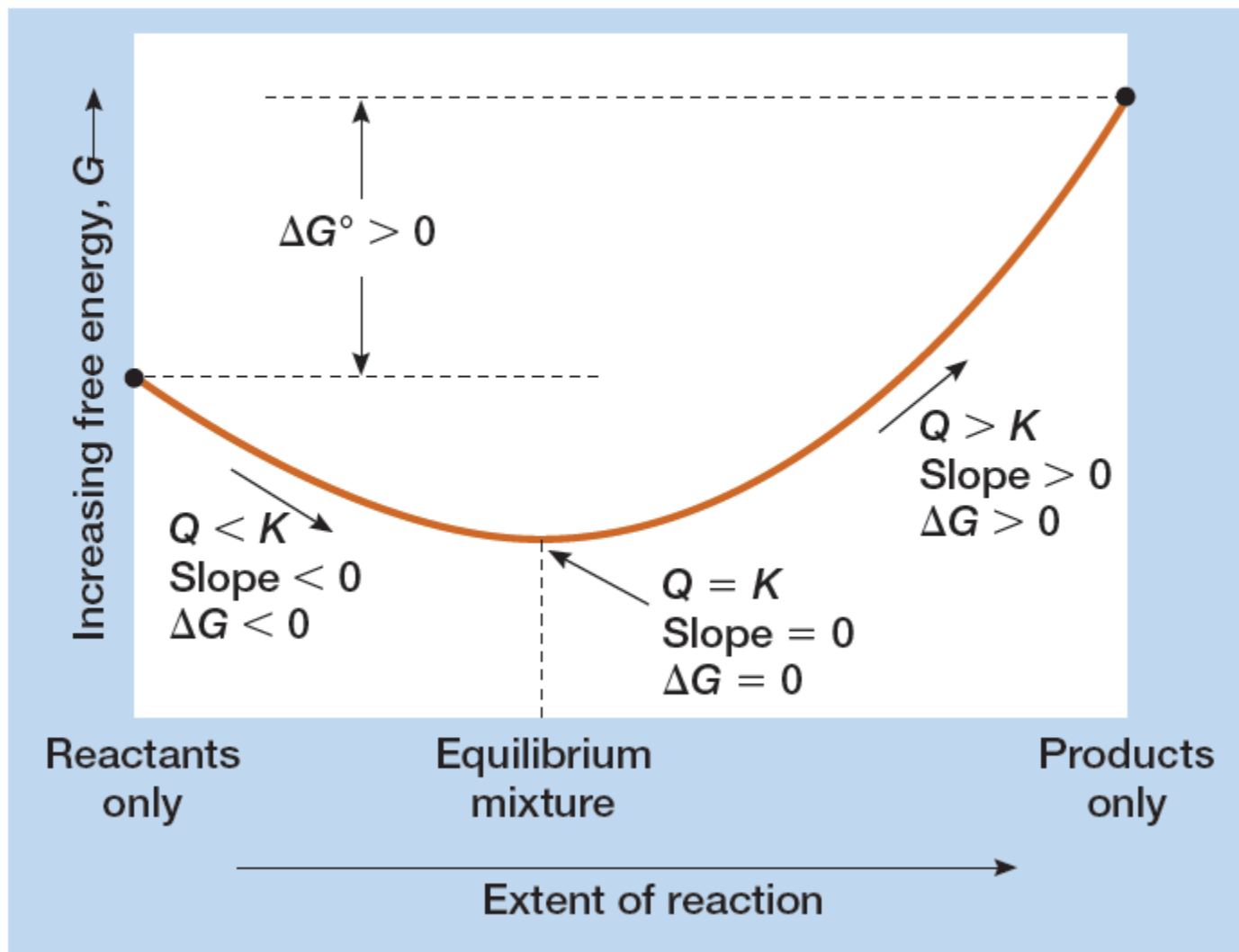
ΔG, ΔG⁰, Q, and K

Can a chemical system have a positive value of ΔG^o and yet still be favored to react in the forward direction?

Reaction is reactant-favored at equilibrium
$\Delta G°$ is positive, $K < 1$

Increasing free energy, G →

$\Delta G° > 0$

$Q < K$
Slope < 0
$\Delta G < 0$

$Q = K$
Slope $= 0$
$\Delta G = 0$

$Q > K$
Slope > 0
$\Delta G > 0$

Reactants only

Equilibrium mixture

Products only

Extent of reaction