9.5 Free Energy and Equilibrium

Name: _____ Class: _____ Date: _____ **Total: 14 marks**

KEY WORDS equilibrium constant • reaction quotient • natural logarithm • gas constant • favored • yield

Objective

Build the skills to answer exam questions on **free energy and equilibrium** : $\Delta G^\circ = -RT \ln K$, and comparing Q with K.

You must be able to:

- use $\Delta G^\circ = -RT \ln K$ with $R = 8.314$ J/(K · mol) and ΔG° in **joules**
- link the sign of ΔG° to K: negative gives $K > 1$, positive gives $K < 1$
- compare Q with K to find the direction a mixture moves
- explain why a fast, unfavored-at-equilibrium process can still be useful

1 Key knowledge and worked examples

■ ΔG° **and** K

ΔG°	K	**at equilibrium**
negative	> 1	products favored
zero	$= 1$	neither favored
positive	< 1	reactants favored

idea	**rule**
the equation	$\Delta G^\circ = -RT \ln K$, so $K = e^{-\Delta G^\circ / RT}$
units	$R = 8.314$ J/(K · mol): change kJ to J
$Q < K$	the reaction goes forward ($\Delta G < 0$ for the forward direction)
$Q > K$	the reaction goes in reverse ($\Delta G > 0$ for the forward direction)

Worked example: from K. $K = 1.0 \times 10^3$ at 298 K.

1. $\Delta G^\circ = -(8.314)(298)\ln(1.0 \times 10^3) = -17\,100$ J/mol.
2. $\Delta G^\circ = -17.1$ **kJ/mol**: negative, as $K > 1$.

Answer shapes: write the equation, convert kJ to J, and comment on the sign.

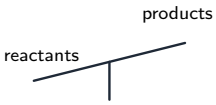
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2 Practice

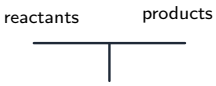
2.1 A reaction has $\Delta G^\circ = -10.0$ kJ/mol at 298 K. Calculate K. [2]



2.2 A reaction has $K = 1.0 \times 10^{-5}$ at 298 K. State the sign of ΔG°, and explain. [2]



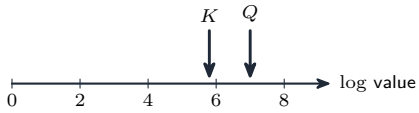
2.3 A reaction has $\Delta G^\circ = 0$ at a certain temperature. State the value of K, and what it means. [2]



3 Exam-style questions

3.1 For $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$, $\Delta G^\circ = -33.0$ kJ/mol at 298 K and $+46.9$ kJ/mol at 700 K.

(a) Calculate K at 298 K. [3]



(b) State whether K at 700 K is greater or less than 1. Explain why factories still run this reaction at about 700 K. [3]

(c) At 298 K, a mixture has $Q = 1.0 \times 10^7$. State the direction the reaction goes, and the sign of ΔG for the forward reaction. [2]

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Solutions

Marking: **M1** a correct method, **A1** the correct answer, **B1** an independent mark.

Each answer shows the steps, then the **result**.

2.1

$K = e^{10\,000/(8.314\times298)} = e^{4.04} = \mathbf{57}$

2.2

positive; $K < 1$, so $\ln K < 0$ and reactants are favored at equilibrium

2.3

$K = \mathbf{1}$; neither reactants nor products are favored at equilibrium

3.1

(a) $\ln K = \dfrac{33\,000}{8.314 \times 298} = 13.3$; $K = \mathbf{6.1 \times 10^5}$

(b) **less than 1**, since ΔG° is positive; at 298 K the rate is far too slow; at 700 K (with a catalyst) equilibrium is reached fast, and high pressure and removing NH_3 raise the yield

(c) $Q > K$, so it goes in **reverse**; ΔG for the forward reaction is **positive**

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