Problems - Chapter 15 (without solutions)

1) What is the significance of the equilibrium constant? What does a large equilibrium constant tell us about a reaction? A small one?

2) (15.18) Write equilibrium constants for K_C, and, if applicable, for K_p, for the following processes:

a) $2\ CO_2(g) \leftrightarrows 2\ CO(g) + O_2(g)$
b) $3\ O_2(g) \leftrightarrows 2\ O_3(g)$
c) $CO(g) + Cl_2(g) \leftrightarrows COCl_2(g)$
d) $H_2O(g) + C(s) \leftrightarrows CO(g) + H_2(g)$
e) $HCOOH(aq) \leftrightarrows H^+(aq) + HCOO^-(aq)$
f) $2\ HgO(s) \leftrightarrows 2\ Hg(\ell) + O_2(g)$

3) The reaction below has an equilibrium constant $K_p = 2.2 \times 10^6$ at 298. K

$2\ COF_2(g) \leftrightarrows CO_2(g) + CF_4(g)$

Calculate K_p for each of the reactions below (at the same temperature) and predict whether reactants or products will be favored at equilibrium

a) $COF_2(g) \leftrightarrows \frac{1}{2}\ CO_2(g) + \frac{1}{2}\ CF_4(g)$
b) $6\ COF_2(g) \leftrightarrows 3\ CO_2(g) + 3\ CF_4(g)$
c) $2\ CO_2(g) + 2\ CF_4(g) \leftrightarrows 4\ COF_2(g)$

4) (15.12) The equilibrium constant for the reaction

$2\ H_2(g) + CO(g) \leftrightarrow CH_3OH(g)$

is $K_C = 1.6 \times 10^{-2}$ at a certain temperature. It is found that there are 1.17×10^{-2} moles of H_2 and 3.46×10^{-7} moles of CH_3OH in a 5.60 L system at equilibrium at this temperature. What is the concentration of CO in the system?

5) Consider the following reaction

$H_2(g) + I_2(g) \leftrightarrows 2\ HI(g)$

Complete the table below. You may assume that all concentrations are equilibrium concentrations in units of mol/L.

T(°C)	$[H_2]$	$[I_2]$	[HI]	K_C
25.0	0.0355	0.0388	0.922	----
340.0	----	0.0455	0.387	96.
445.0	0.0485	0.0468	----	50.2

6) (15.24) What is the numerical value for K_p at T = 1273. °C for the reaction

$$2\ CO(g) + O_2(g) \leftrightarrows 2\ CO_2(g)$$

At this temperature $K_C = 2.24 \times 10^{22}$.

7) (15.34) The following equilibrium constants have been determined for hydrosulfuric acid at T = 25.0 °C

$$H_2S(aq) \leftrightarrows H^+(aq) + HS^-(aq) \qquad K_C' = 9.5 \times 10^{-8}$$

$$HS^-(aq) \leftrightarrows H^+(aq) + S^{2-}(aq) \qquad K_C'' = 1.0 \times 10^{-19}$$

Find the equilibrium constant for the following reaction at the same temperature

$$H_2S(aq) \leftrightarrows 2\ H^+(aq) + S^{2-}(aq) \qquad K_C = ?$$

8) For the reaction below, K_C = 255. at T = 1000. K

$$CO(g) + Cl_2(g) \leftrightarrows COCl_2(g)$$

A reaction mixture (kept at T = 1000. K) initially contains no $COCl_2$. The initial concentrations of CO and Cl_2 are [CO] = 0.1500 M, and [Cl_2] = 0.1750 mol/L. What are the equilibrium concentrations of CO, Cl_2, and $COCl_2$?

9) Consider the reaction

$$SO_2Cl_2(g) \leftrightarrows SO_2(g) + Cl_2(g) \qquad K_C = 2.99 \times 10^{-7} \text{ at T} = 227.\ °C$$

If the reaction (kept at T = 227. °C) initially contains 0.175 mol/L SO_2Cl_2 (and no SO_2 or Cl_2), what is the equilibrium concentration of Cl_2?

10) The equilibrium constant for the reaction

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

is $K_C = 6.9 \times 10^5$ at T = 500. K. Consider a system at this temperature where the initial concentration of NO_2 is [NO_2] = 0.1000 mol/L, and where no NO or O_2 are initially present. What are the concentrations of NO, O_2, and NO_2 when equilibrium is reached?

11) In which direction will a reaction proceed for each of the following conditions:
a) Q < K b) Q > K c) Q = K

12) Consider the reaction

$2\ H_2S(g) \leftrightarrows 2\ H_2(g) + S_2(g)$ $\quad K_p = 2.4 \times 10^{-4}$ at T = 1073. K

A reaction mixture contains 0.112 atm of H_2, 0.055 atm of S_2, and 0.445 atm of H_2S. Is the reaction mixture at equilibrium? If not, in what direction will the reaction proceed?

13) Consider this reaction at equilibrium

$2\ BrNO(g) \leftrightarrows 2\ NO(g) + Br_2(g)$

Predict whether the reaction will shift left, shift right, or remain unchanged after each disturbance.

a) NO is added to the reaction mixture.
b) BrNO is added to the reaction mixture.
c) Br_2 is removed from the reaction mixture.

14) Each of the following reactions is allowed to come to equilibrium, and the volume is then changed as indicated. Predict the effect (shift right, shift left, or no effect) of the indicated volume change.

a) $CO(g) + H_2O(g) \leftrightarrows CO_2(g) + H_2(g)$ volume is decreased
b) $PCl_3(g) + Cl_2(g) \leftrightarrows PCl_5(g)$ volume is increased
c) $CaCO_3(s) \leftrightarrows CaO(s) + CO_2(g)$ volume is increased

15) (15.86) Consider the following reaction

$A(g) \leftrightarrows 2\ B(g)$

Data for this reaction for systems at equilibrium are given below.

T(°C)	[A] (M)	[B] (M)
200.0	0.0125	0.843
300.0	0.171	0.764
400.0	0.250	0.724

a) Find the value for K_C and K_p at each of the above temperatures.
b) Is the above reaction exothermic or endothermic? Justify your answer.

16) (15.47) Find $\Delta G°$ and K for the following equilibrium reaction at T = 25. °C

$PCl_5(g) \leftrightarrows PCl_3(g) + Cl_2(g)$

Also find ΔG for the reaction if $p(PCl_5) = 0.0029$ atm, $p(PCl_3) = 0.27$ atm, and $P(Cl_2) = 0.40$ atm.

17) (15.50) The equilibrium constant for the reaction

$$CO(g) + Cl_2(g) \leftrightarrow COCl_2(g)$$

is 5.62×10^{35} at T = 25. °C. Using only this information find the value for $\Delta G°_{rxn}$ for this process at this temperature.

18) The gas phase reaction of sulfur dioxide (SO_2) with molecular oxygen (O_2) can produce sulfur trioxide (SO_3). The balanced equation for the reaction is

$$2\ SO_2(g) + O_2(g) \leftrightarrows 2\ SO_3(g)$$

Thermodynamic data for the reactants and products are given below, at T = 25. °C.

Substance	$\Delta H°_f$ (kJ/mol)	$\Delta G°_f$ (kJ/mol)	S° (J/mol·K)
$O_2(g)$	0.0	0.0	205.2
$SO_2(g)$	- 296.8	- 300.1	248.2
$SO_3(g)$	- 395.7	- 371.1	256.8

Based on this information find $\Delta G°_{rxn}$ and K for the above reaction at T = 25. °C

19) The equilibrium constant for the reaction

$$C(s) + CO_2(g) \leftrightarrows 2\ CO(g)$$

measured at T = 850. °C, is $K_p = 1.2 \times 10^{14}$.

A system initially has $p_{CO} = 0.400$ atm and $p_{CO2} = 0.300$ atm. What are the pressures of CO and CO_2 when the system reaches equilibrium?