Chapter 6: Chemical Equilibrium

1. Given the two reactions shown with their equilibrium constants,

$$\mathbf{PCl_3(\mathit{g}) + Cl_2(\mathit{g}) \rightleftharpoons PCl_5(\mathit{g})} \qquad K_1$$
$$\mathbf{2\,NO(\mathit{g}) + Cl_2(\mathit{g}) \rightleftharpoons 2\,NOCl(\mathit{g})} \qquad K_2$$

What is the equilibrium constant for the reaction,

$$\mathbf{PCl_5(\mathit{g}) + 2\,NO(\mathit{g}) \rightleftharpoons PCl_3(\mathit{g}) + 2\,NOCl(\mathit{g})}$$

a. K_1K_2
* b. K_2/K_1 (flip first equation and added to the second equation)
c. K_1/K_2
d. $(K_1K_2)^{-1}$
e. K_2-K_1

2. The equilibrium constant for the reaction, $\mathbf{H_2(\mathit{g}) + I_2(\mathit{g}) \rightleftharpoons 2\,HI(\mathit{g})}$ is 54.9 at 699.0 K. What is the equilibrium constant for $\mathbf{4\,HI(\mathit{g}) \rightleftharpoons 2\,H_2(\mathit{g}) + 2\,I_2(\mathit{g})}$ under the same conditions?

a. 109.8
b. 0.00911
* c. 0.000332 $K_2 = (1/K_1)^2 = (1/54.9)^2 = 3.32 \times 10^{-4} = 0.000332$
d. -109.8
e. 0.0182

3. Using this data,

$$\mathbf{2\,NO(\mathit{g}) + Cl_2(\mathit{g}) \rightleftharpoons 2\,NOCl(\mathit{g})} \qquad \mathbf{K_{c1} = 3.20 \times 10^{-3}}$$
$$\mathbf{2\,NO_2(\mathit{g}) \rightleftharpoons 2\,NO(\mathit{g}) + O_2(\mathit{g})} \qquad \mathbf{K_{c2} = 15.5}$$

Calculate a value for K_c for the reaction,

$$\mathbf{NOCl(\mathit{g}) + ½\,O_2(\mathit{g}) \rightleftharpoons NO_2(\mathit{g}) + ½\,Cl_2(\mathit{g})}$$

a. 2.06×10^{-4}
b. 4.84×10^{-3}
c. 0.223
* d. 4.49 flip and multiply eq 1 by (1/2) then do the same for eq2. Add two eq.
e. 20.2 $K = (1/K_1)^{1/2} \cdot (1/K_2)^{1/2} = (1/3.20 \times 10^{-3})^{1/2} \times (1/15.5)^{1/2} = 4.49$

4. For which one of the following reactions is K_p equal to K_c? when Δn(gases) =0

a. $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$
b. $C(s) + CO_2(g) \rightleftharpoons 2CO(g)$
* c. $6CO_2(g) + 6H_2O(l) \rightleftharpoons C_6H_{12}O_6(s) + 6O_2(g)$
d. $CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$
e. $H_2O(g) + C(s) \rightleftharpoons H_2(g) + CO(g)$

5. For the reaction, $\mathbf{2SO_2(\mathit{g}) + 1O_2(\mathit{g}) \rightleftharpoons 2SO_3(\mathit{g})}$, at 900.0 K the equilibrium constant, K_c, has a value of 13.0. Calculate the value of K_p at the same temperature.

a. 97.3×10^3

* b. 0.176 $K_p = K_c (RT)^{\Delta n} = 13 \times (0.082 \times 900)^{-1} = 13/(0.082 \times 900) = 0.176$

c. 960

d. 0.00174

e. 0.077

6. Write the mass action expression for the following reaction:

$$\mathbf{4Cr(\mathit{s}) + 3CCl_4(\mathit{g}) \rightleftharpoons 4CrCl_3(\mathit{g}) + 4C(\mathit{s})}$$

a. $K_c = \dfrac{[C][CrCl_3]}{[Cr][CCl_4]}$

b. $K_c = \dfrac{[C]^4[CrCl_3]^4}{[Cr]^4[CCl_4]^3}$

* c. $K_c = \dfrac{[CrCl_3]^4}{[CCl_4]^3}$

d. $K_c = \dfrac{[CrCl_3]}{[CCl_4]}$

e. $K_c = [CrCl_3]^4 + [CCl_4]^3$

7. Consider the following system, which is at equilibrium,

$\mathbf{CO(\mathit{g}) + 3H_2(\mathit{g}) \rightleftharpoons CH_4(\mathit{g}) + H_2O(\mathit{g})}$. (will shift to right side)

The result of removing some $CH_4(g)$ and $H_2O(g)$ from the system is that

* a. more $CH_4(g)$ and $H_2O(g)$ are produced to replace that which is removed

b. K_c decreases

c. more $CO(g)$ is produced

d. more $H_2O(g)$ is consumed to restore the equilibrium

e. more $CH_4(g)$ is consumed to restore the equilibrium

8. The following reactions have equilibrium values all measured at 500 K. Arrange them in order of increasing tendency to proceed to completion (least completion $\rightarrow$ greatest completion).

1) $2NOCl \rightleftharpoons 2NO + Cl_2$ $K_p = 1.7 \times 10^{-2}$

2) $N_2O_4 \rightleftharpoons 2NO_2$ $K_p = 1.5 \times 10^{3}$

3) $2SO_3 \rightleftharpoons 2SO_2 + O_2$ $K_p = 1.3 \times 10^{-5}$

4) $2NO_2 \rightleftharpoons 2NO + O_2$ $K_p = 5.9 \times 10^{-5}$

a. 2 < 1 < 3 < 4

b. 4 < 3 < 1 < 2

c. 3 < 1 < 4 < 2

* d. 3 < 4 < 1 < 2 from smaller no to a larger one of K_p

e. 4 < 3 < 2 < 1

9. The reaction, Q + **2 $SO_3(g)$ $\rightleftharpoons$ 2 $SO_2(g)$ + $O_2(g)$** is endothermic. Predict what will happen if the temperature is increased.

a. K_c remains the same

b. K_c decreases

c. the pressure decreases

d. more $SO_3(g)$ is produced

* e. K_c increases T increase, reaction will shift to right side and K_c increase

10. Consider the following system, which is at equilibrium,

$$CO(g) + 3H_2(g) \rightleftharpoons CH_4(g) + H_2O(g).$$

The result of removing some $CH_4(g)$ and $H_2O(g)$ from the system is that

* a. more $CH_4(g)$ and $H_2O(g)$ are produced to replace that which is removed

b. K_c decreases

c. more $CO(g)$ is produced

d. more $H_2O(g)$ is consumed to restore the equilibrium

e. more $CH_4(g)$ is consumed to restore the equilibrium

11. The system, **$2H_2O(g) + 2Cl_2(g) \rightleftharpoons 4HCl(g) + O_2(g)$**, has a value of 8.00 for K_p. Initially, the partial pressures of $H_2O(g)$ and $Cl_2(g)$ are set at 0.100 atm, while those of $HCl(g)$ and $O_2(g)$ are set at 0.250 atm. Which statement below is true?

$Q = (0.250)^4 /(0.1)^4 = 39.06$, Q > K, Q must decrease, will shift to left side

a. $Q_p > K_p$ and the reaction proceeds to the right to reach equilibrium.

b. $Q_p < K_p$ and the reaction proceeds to the left to reach equilibrium.

c. The reaction system is already at equilibrium.

* d. $Q_p > K_p$ and the reaction proceeds to the left to reach equilibrium.

e. $Q_p < K_p$ and the reaction proceeds to the right to reach equilibrium.

12. A study of the system, **$4NH_3(g) + 7O_2(g) \rightleftharpoons 2N_2O_4(g) + 6H_2O(g)$,** was carried out. A system was prepared with $[NH_3] = [O_2] = 3.60$ M as the only components initially. At equilibrium, $[N_2O_4]$ is 0.60 M. Calculate the equilibrium concentration of O_2.

a. 3.00 M

b. 2.40 M

* c. 1.50 M

d. 2.10 M

e. 3.30 M

	$4NH_3(g) + 7O_2(g) \rightleftharpoons$		$2N_2O_4(g)$	$+ 6H_2O(g)$
I	3.6	3.6	0	0
C	4x	7x	2x	6x
E	3.6-4x	3.6-7x	2x	6x
2x=0.6 x=0.3		3.6-7(0.3)= 1.5 M		

13. For the reaction system, $\mathbf{2SO_2(\mathit{g}) + O_2(\mathit{g}) \rightleftharpoons 2SO_3(\mathit{g})}$, the equilibrium concentrations are: SO_3: 0.120M SO_2: 0.860M O_2: 0.330M. Calculate the value of K_c for this reaction.

$Kc = [SO_3]^2 /[SO_2]^2 [O_2] = (0.120)^2 / (0.860)^2 (0.330) =0.05899$

a. 1.31
b. 2.51
c. 0.423
d. 0.872
* e. 0.0590

14. At 1500 °C the system, $\mathbf{2NO(\mathit{g}) \rightleftharpoons N_2(\mathit{g}) + O_2(\mathit{g})}$, was allowed to come to equilibrium. The equilibrium concentrations were: NO(g) = 0.00035 M, $N_2(g)$ = 0.040 M, and $O_2(g)$ = 0.040 M. What is the value of K_c for the system at this temperature?

$Kc = [N_2] [O_2] /[NO]^2 = (0.040) (0.040) / (0.00035)^2 = 13061=1.3 \times 10^4$

a. 1.5×10^{-6}
b. 7.7×10^{-5}
c. 2.2×10^{-1}
d. 4.6
* e. 1.3×10^4

15. A chemical system is considered to have reached equilibrium when

a. the rate of consumption of each of the product species by the reverse reaction is equal to the rate of production of each of the reactant species by the reverse reaction.

b. the sum of the concentrations of each of the reactant species is equal to the sum of the concentrations of each of the product species.

* c. the rate of production of each of the product species is equal to the rate of consumption of each of the product species by the reverse reaction.

d. the rate of production of each of the product species is equal to the rate of consumption of each of the reactant species by the reverse reaction.

e. the rate of production of each of the product species by the forward reaction is equal to the rate of production of each of the reactant species by the reverse reaction.

16. The system, **2NO(*g*) $\rightleftharpoons$ N$_2$(*g*) + O$_2$(*g*)** was allowed to come to equilibrium at 1500 ^oC. The equilibrium concentrations were: NO(*g*) = 0.00035 M, N$_2$(*g*) = 0.040 M, and O$_2$(*g*) = 0.040 M. What is the value of K_p for the system at this temperature?

$Kc = [N_2]\,[O_2]\ /[NO]^2 = (0.040)\,(0.040)\ /\ (0.00035)^2 = 13061 = 1.3 \times 10^4$

$K_p = K_c\,(RT)^{\Delta n} = 1.3 \times 10^4\,(0.082 \times 1773)^0$ then $K_p = K_c = 1.3 \times 10^4$

a. 2.2×10^{-1}

* b. $1.3 \times 10^{+4}$

c. $1.9 \times 10^{+6}$

d. 7.7

e. 1.5

17. A study of the system, **4 NH$_3$(*g*) + 7 O$_2$(*g*) $\rightleftharpoons$ 2 N$_2$O$_4$(*g*) + 6 H$_2$O(*g*),** was carried out. A system was prepared with [NH$_3$] = [O$_2$] = 3.60 M as the only components initially. At equilibrium, [N$_2$O$_4$] is 0.60 M. Calculate the value of the equilibrium constant, K_c, for the reaction.

		4NH$_3$(*g*)	**+ 7O$_2$(*g*)**	**$\rightleftharpoons$ 2N$_2$O$_4$(*g*)**	**+ 6H$_2$O(*g*)**
	I	3.6	3.6	0	0
	C	4x	7x	2x	6x
	E	3.6-4x	3.6-7x	2x	6x
2x=0.6	x=0.3	3.6-4(0.3)	3.6-7(0.3)	0.6	6 x 0.3
	[ ]$_{eq}$	2.4	1.5	0.6	1.8

$K = (1.8)^6\,(0.6)^2 / (1.5)^7\,(2.4)^4 \qquad K = 0.0216$

a. 8.1

b. 0.0000093

c. 0.30

* d. 0.022

e. 3.3

18. Given the reaction, **2NO(*g*) + O$_2$(*g*) $\rightleftharpoons$ 2NO$_2$(*g*) + Q**, for which the enthalpy of reaction is -118.9 kJ. Which one of the following actions will cause an increase in the equilibrium concentration of NO(*g*) in a closed reaction chamber?

Will shift to the left by increasing T

a. adding more O$_2$(*g*) through an injection nozzle

* b. increasing the temperature of the system

c. removing the NO$_2$(g) from the system

d. increasing the pressure of the system while temperature is kept constant

e. adding a catalyst