CHM152 – Chapter 13: Chemical Equilibrium – Homework-KEY

1. Which one of these statements does not describe the equilibrium state?
   a. Equilibrium is dynamic and there is no net conversion to reactants and products.
   b. The concentration of the reactants is equal to the concentration of the products.
   c. The concentration of the reactants and products reach a constant level.
   d. The rate of the forward reaction is equal to the rate of the reverse reaction.

2. Write K_C, the equilibrium equation for the forward reaction:
   $2\ CH_4\ (g) + 3\ O_2\ (g) \rightleftharpoons 2\ CO\ (g) + 4\ H_2O\ (g)$ $\quad K_C = \dfrac{[H_2O]^4[CO]^2}{[O_2]^3[CH_4]^2}$

3. Nitric oxide (NO) reacts with oxygen to form nitrogen dioxide. What is K_C for the forward reaction if the equilibrium concentration of NO is 0.200 M, O_2 is 0.100 M, and NO_2 is 0.250 M at 25°C?
   $K_C = \dfrac{(0.250)^2}{(0.200)^2(0.100)} = 15.6$

4. If $K_C = 1.5 \times 10^{-5}$ at 35°C is the equilibrium constant for the forward reaction what is K_C' for the reverse reaction at the same temperature? $K_C' = \dfrac{1}{K_C} = 6.7 \times 10^4$

5. Write K_P', the equilibrium equation for the reverse reaction:
   $2\ CH_4\ (g) + 3\ O_2\ (g) \rightleftharpoons 2\ CO\ (g) + 4\ H_2O\ (l)$ (Hint: notice the physical states!)
   $K_P' = \dfrac{(P_{CH4})^2(P_{O2})^3}{(P_{CO})^2}$

6. Calculate K_P' for the reaction in question #5 if the partial pressures are 0.122 atm for CH_4, 0.333 atm for O_2, and 0.564 atm for CO.
   $K_P' = \dfrac{(P_{CH4})^2(P_{O2})^3}{(P_{CO})^2} = \dfrac{(0.122)^2(0.333)^3}{(0.564)^2} = 1.73 \times 10^{-3}$

7. What is K_C at 25°C for the reaction in problem #6?
   First find $K_P = 579$. $K_C = \dfrac{K_P}{(RT)^{\Delta n}}$ Recall $\Delta n = (2) - (2 + 3) = -3$

8. At a certain temperature, the reaction $PCl_5\ (g) \rightleftharpoons PCl_3\ (g) + Cl_2\ (g)$ has an equilibrium constant $K_C = 5.8 \times 10^{-2}$. If the initial concentrations are 0.200 M for PCl_5, 0.100 M for PCl_3, and 0.040 M for Cl_2, which direction will the reaction shift until it reaches equilibrium? What are the equilibrium concentrations of all the species?
   $Q_C = 0.0200$ which is smaller than K_C so the reaction will shift towards the products until equilibrium is reached.
   Set up an ICE table:

	$PCl_5\ (g)$	$\rightleftharpoons$	$PCl_3\ (g)$	+	$Cl_2\ (g)$
	0.200M		0.100 M		0.040 M
	-x		+x		+x
	(0.200 – x)		(0.100 + x)		(0.040 + x)

   $K_C = 5.8 \times 10^{-2} = \dfrac{(0.100 + x)(0.040 + x)}{(0.200 - x)}$ Use the quadratic formula to solve for x. x = 0.033 M
   Substitute x in and $[PCl_5] = 0.167$ M, $[PCl_3] = 0.133$M, $[Cl_2] = 0.073$ M

9. The decomposition of sulfur trioxide is: $2\ SO_3\ (g) \rightleftharpoons O_2\ (g) + 2\ SO_2\ (g)$. If K_C is 0.200 at 1300 K, what is the partial pressure of SO_3 at equilibrium when O_2 (g) is 0.18 atm and SO_2 (g) is 0.25 atm?
   Find K_P first: $K_P = K_C(RT)^{\Delta n} = 21.3$ $\quad 21.3 = \dfrac{(0.25)^2(0.18)}{x^2}$ so x = 0.023 atm

10. At a certain temperature the equilibrium constant, K_C, equals 0.11 for the reaction:
    $2\ HF\ (g) \rightleftharpoons F_2\ (g) + H_2\ (g)$
    What is the equilibrium concentration of HF if 0.75 mol of H_2 and 0.75 mol of F_2 are initially mixed in a 2.0 L flask?
    Set up an ICE table:

	$2\ HF\ (g)$	$\rightleftharpoons$	$F_2\ (g)$	+	$H_2\ (g)$
	0		0.38 M		0.38 M
	+2x		-x		-x
	2x		(0.38 - x)		(0.38 - x)

    $K_C = 0.11 = \dfrac{(0.38 - x)(0.38 - x)}{(2x)^2}$ Use the quadratic formula to solve for x. x = 0.223 M (not 0.64 M – too big!))
    Substitute x in and [HF] = 0.45 M

11. The air pollutant NO is produced in automobile engines from the high-temperature reaction

$N_2(g) + O_2(g) \rightleftharpoons 2\,NO(g)$ $K_C = 1.70 \times 10^{-3}$ at 2300 K

Calculate the equilibrium concentrations of N_2, O_2, and NO if 314 g of N_2 and 89.6 g of O_2 are initially placed in a 5.00 L flask.

$N_2(g) + O_2(g) \rightleftharpoons 2\,NO(g)$

(2.24 M) (0.560 M)

- x -x +2x $1.7 \times 10\text{-}3 = \dfrac{4x^2}{(2.24\text{ M} - x)(0.560\text{M} - x)} = x = 0.023$ M

$[N_2] = 2.24 - 0.023 = 2.22$ M, $[O_2] = 0.54$ M, $[NO] = 0.046$ M

12. Gaseous hydrogen bromide decomposes at elevated temperatures according to the following equation:

$2\,HBr(g) \rightleftharpoons H_2(g) + Br_2(g)$

At a certain temperature a 5.00 L flask is initially filled only with 0.600 mol of HBr. What is the value of K_c at that temperature if the flask contains 0.104 mol of H_2 at equilibrium?

Set up an ICE table: $2\,HBr(g) \rightleftharpoons H_2(g) + Br_2(g)$

0.300M

-2x +x +x

0.300 - 2x 0.052 M 0.052 M

$K_C = \dfrac{(0.052M)(0.052\ M)}{(0.196M)^2} = 7.04 \times 10^{-2}$

13. When reaction (1) and (2) below are added together, the result is reaction (3).

(1) $H_2O(l) + HNO_2(aq) \rightleftharpoons H_3O^+(aq) + NO_2^-(aq)$

(2) $H_3O^+(aq) + OH^-(aq) \rightleftharpoons 2\,H_2O(l)$

(3) $HNO_2(aq) + OH^-(aq) \rightleftharpoons NO_2^-(aq) + H_2O(l)$

If $K_1 = 4.50 \times 10^{-4}$, and $K_2 = 1.00 \times 10^{14}$, find the equilibrium constant, K_3.

$(4.50 \times 10^{-4})(1.00 \times 10^{14}) = 4.50 \times 10^{10}$

14. Which of the following changes in reaction conditions will not alter the equilibrium concentrations?

a. addition of an inert gas to the reaction mixture
b. addition of reactants or products
c. decreasing the pressure or volume
d. increasing the temperature

15. The overall reaction for photosynthesis can be represented by the following equation:

$6\,CO_2(g) + 6\,H_2O(l) \rightleftharpoons C_6H_{12}O_6(s) + 6\,O_2(g)$

The enthalpy change for this reaction is 2802 kJ.

How will the equilibrium shift (right, left, no change) with the following changes:

a. increase in temperature right
b. increase the pressure of O_2 left
c. remove CO_2 left
d. add $C_6H_{12}O_6$ no change

16. How will the following changes shift the equilibrium for the reaction:

$N_2O_5(g) \rightleftharpoons NO_2(g) + NO_3(g)$

a. decreasing the amount of NO_3 right
b. increasing the amount of N_2O_5 right
c. increasing the pressure left
d. increasing the volume right

17. A crude type of disappearing ink is based on the following exothermic equilibrium:

$[CoCl_2(H_2O)_4](aq) + 2\,H_2O(g) \rightleftharpoons [Co(H_2O)_6]Cl_2(aq)$

(blue) (colorless)

If the product solution is used to write on a piece of paper and the paper is allowed to partially dry, what can be done to bring out the colored handwriting?

a. add water
b. decrease the volume
c. put the paper in the freezer
d. put the paper in the oven