Spring 2008 CH 302 Worksheet 3

Below are listed various reactions, stresses, and reaction components. Indicate how the amount of the indicated component changes when the stress is applied.

	Reaction	Stress	Component
1.	$3\ H_2\ (g) + N_2\ (g) \leftrightarrow 2\ NH_3\ (g)$	Addition of N_2 gas	H_2
	Answer: The amount of H_2 **decreases**, because the reaction shifts to the right to decrease the amount of N_2 present (adding N_2 decreases Q).		
2.	$CH_3OH\ (g) + 2\ O_2\ (g) \leftrightarrow CO_2\ (g) + 2\ H_2O\ (g)$	Addition of heat	CH_3OH
	Answer: The amount of CH_3OH **increases**, because this combustion reaction releases heat; therefore, it goes in reverse to consume heat.		
3.	$CH_3OH\ (g) + H_2\ (g) \leftrightarrow CH_4\ (g) + H_2O\ (l)$	Addition of pressure	CH_3OH
	Answer: The amount of CH_3OH **decreases**, because the reaction shifts to the right to decrease the pressure in the system; remember that liquids don't contribute to pressure.		
4.	$N_2\ (g) + O_2\ (g) \leftrightarrow 2\ NO\ (g)$	Reduction of pressure	O_2
	Answer: The amount of O_2 **does not change**, because the reaction cannot shift to increase the pressure in the system (there are equal amounts of gas on each side).		

Give the equation for K_c for the equations given in problems 5-8.

5. $2\ H_2\ (g) + 2\ O_2\ (g) \leftrightarrow 2\ H_2O\ (g)$

   Answer: $\mathbf{K_c = [H_2O]^2/[H_2]^2[O_2]^2}$

6. $HCl\ (aq) + H_2O\ (l) \leftrightarrow H_3O^+\ (aq) + Cl^-\ (aq)$

   Answer: $\mathbf{K_c = [H_3O^+][Cl^-]/[HCl]}$

7. $NaCl\ (s) \leftrightarrow Na^+\ (aq) + Cl^-\ (aq)$

   Answer: $\mathbf{K_c = [Na^+][Cl^-]}$ (This is known as Ksp, the solubility product for NaCl.)

8. $C_8H_{18}\ (g) + 25/2\ O_2\ (g) \leftrightarrow 8\ CO_2\ (g) + 9\ H_2O\ (g)$

   Answer: $\mathbf{K_c = [CO_2]^8[H_2O]^9/[C_8H_{18}]^2[O_2]^{25/2}}$

9. Consider the following reaction at 25°C:

   $$H_2 + I_2 \leftrightarrow 2\ HI$$

   The reaction mixture is initially prepared with $C_{H2} = 0.1$, $C_{I2} = 0.1$, $C_{HI} = 0.5$. What is Q for this initial reaction mixture?

   Answer: $Q = C_{HI}^2/C_{H2}C_{I2} = (0.5)^2/(0.1 \cdot 0.1) = \mathbf{25}$

10. Which direction will the reaction in number 7 shift, given $K_c = 60.2$?

    Answer: Since Q < Kc, the reaction will shift to the **right**.

11. For the reaction

    $$N_2\ (g) + 3\ H_2\ (g) \leftrightarrow 2\ NH_3\ (g)$$

    the equilibrium constant with respect to concentration, $K_c = 3.8$. Calculate K_p at 298 K, the equilibrium constant with respect to pressure in atm. (Note: This hasn't been covered in class yet and won't be on Tuesday's quiz.)

    Answer: $K_p = K_c(RT)^{\Delta n} = 3.8[(0.0821\ Latm/molK)(298K)]^{2-4} = 0.00635$

12. For the reaction

    $$NH_3\ (g) + HCl\ (g) \leftrightarrow NH_4Cl\ (s)$$

    $\Delta H = -176$ kJ/mol and $\Delta S = -305$ J/mol K. What is K for this reaction a 300 K? At 600 K?

    Answer:

    At 300 K: $\Delta G = -176\ kJ/mol - (300\ K)(-.305\ kJ/mol\ K) = -84.5\ kJ$

    $K = \exp(-\Delta G/RT) = \exp[-(-84500\ J/mol)/(8.314\ J/mol\ K \cdot 300\ K)]$

$K = 5.17 \cdot 10^{14}$

At 600 K: Similar calculations yield K = **0.246**

13. Calculate ΔG for the formation of ammonia at 298 K, given $K_c = 3.8$.

Answer: ΔG = -RT ln K = -(8.314 J/mol K)(298 K) ln(3.8) = **-3.308 kJ/mol**

14. Assume that at some temperature, the reaction given below has an equilibrium constant K_p of 7.5. $C_6H_{12}O_6$, O_2, CO_2, and H_2O are places in a reaction vessel, each with an initial concentration of 1 atm. What are the equilibrium pressures?

$$C_6H_{12}O_6\ (g) + 6\ O_2\ (g) \leftrightarrow 6\ CO_2\ (g) + 6\ H_2O\ (g)$$

a. $P_{C6H12O6} = 1.017$, $P_{O2} = 1.108$, $P_{CO2} = 0.892$, $P_{H2O} = 0.891$
b. $P_{C6H12O6} = 0.898$, $P_{O2} = 0.387$, $P_{CO2} = 1.613$, $P_{H2O} = 1.613$
c. $P_{C6H12O6} = 0.981$, $P_{O2} = 0.887$, $P_{CO2} = 1.112$, $P_{H2O} = 1.112$
d. $P_{C6H12O6} = 1.465$, $P_{O2} = 1.465$, $P_{CO2} = 0.535$, $P_{H2O} = 0.535$

Answer: Plug the given values in and check. Because K > 1, answers a and d can be eliminated immediately.

15. Write an expression for K_p for the reaction in problem 14 above, in terms of x = the magnitude of the change in pressure of $C_6H_{12}O_6$.

Answer: $$Ksp = \frac{(1 + 6x)^6(1 + 6x)^6}{(1 - x)(1 - 6x)^6}$$

16. Assume that the reaction below has an equilibrium constant of 105 at some temperature. If you start out with 1 M CO_2 and 1 M H_2 in 3 kg of water, what is the equilibrium concentration of CO?

$$CO\ (aq) + H_2O\ (l) \leftrightarrow CO_2\ (aq) + H_2\ (aq)$$

Answer:

CO (aq)	H_2O (l)	CO_2 (aq)	H_2 (aq)
0	XXXXX	1	1
+x	XXXXX	-x	-x
x	XXXXX	1-x	1-x

K = 105 = (1-x)(1-x)/x

$105x = x^2 - 2x + 1$

$x^2 - 107x + 1 = 0$

By the quadratic formula, x = 107 or x = 0.00935. If x = 107, $[CO_2]$ and $[H_2]$ would be negative, so **[CO] = x = 0.00935 M**.

17. For the same reaction as in number 14, imagine you have some mixture of CO, CO_2, and H_2 in water. You know that initially $C_{CO} = 0.0025$ M and $C_{H2} = 0.5$ M. The equilibrium concentration of CO_2 ends up being 0.005. What are the initial and final concentrations of CO_2 in this reaction?

Answer:

CO (aq)	H2O (l)	CO2 (aq)	H2 (aq)
0.0025	XXXXX	x	0.5
+0.0025	XXXXX	-0.0025	-0.0025
0.005	XXXXX	x-0.0025	0.4975

K = 105 = (x-0.0025)(0.4975)/(0.005)

0.525 = 0.4975x – 0.00124375

x = 1.05778

So **initial C_{CO2} = 1.05778 M, final $[CO_2]$ = 1.05528 M**

18. One mole of acetic acid is dissolved in one liter of water, following the reaction below. K for this process, known as the "acid dissociation constant" for acetic acid, is about 1.8 x 10^{-5}. Given that the pH of a solution is defined by
pH = $-\log_{10}([H_3O^+])$, what is the pH of this solution at equilibrium?

$$HC_2H_3O_2\ (aq) + H_2O\ (l) \leftrightarrow C_2H_3O_2^-\ (aq) + H_3O^+\ (aq)$$

Answer:

$HC_2H_3O_2$ (aq)	H_2O (l)	$C_2H_3O_2^-$ (aq)	H_3O^+ (aq)
1	XXXXX	0	0
-x	XXXXX	+x	+x
1-x	XXXXX	x	x

$K = 1.8 \times 10^{-5} = x^2/(1-x)$
$(1.8 \times 10^{-5}) - (1.8 \times 10^{-5})x = x^2$
$x^2 + (1.8 \times 10^{-5})x - (1.8 \times 10^{-5}) = 0$
x = 0.00423 M
pH = $-\log_{10}([H_3O^+]) = -\log_{10}(x) = -\log_{10}(0.00423)$ = **2.37**

19. Imagine some reaction A ↔ A*, which converts some species A between two forms. The reaction takes place in solution. If 1 mole of each of A and A* is placed in 1 L of water, and K for the reaction as written is 1.5, what is the equilibrium concentration of A*?

Answer:

A	A*
1	1
-x	+x
1-x	1+x

K = 1.5 = (1+x)/(1-x)
1.5 -1.5x = 1 + x
.5 = 2.5 x
x = 0.2
[A*] = 1 + 0.2 = 1.2 M

20. Once the reaction in problem 19 has reached equilibrium, 90% of the A* is removed from the mixture, and equilibrium is reestablished. What is the new concentration of A*?

Answer:

A	A*
0.8	0.12
-x	+x
0.8-x	0.12+x

K = 1.5 = (0.12+x)/(0.8-x)
1.2 – 1.5 x = 0.12 + x
1.08 = 2.5 x
x = 0.432
[A*] = 0.12 + 0.432 = 0.552 M