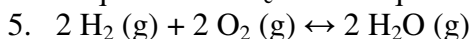


### Spring 2008 CH 302 Worksheet 3

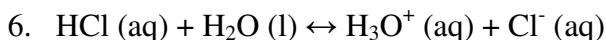
Below are listed various reactions, stresses, and reaction components. Indicate how the amount of the indicated component changes when the stress is applied.

	Reaction	Stress	Component
1.	$3 \text{H}_2 (\text{g}) + \text{N}_2 (\text{g}) \leftrightarrow 2 \text{NH}_3 (\text{g})$ Answer: The amount of $\text{H}_2$ <b>decreases</b> , because the reaction shifts to the right to decrease the amount of $\text{N}_2$ present (adding $\text{N}_2$ decreases Q).	Addition of $\text{N}_2$ gas	$\text{H}_2$
2.	$\text{CH}_3\text{OH} (\text{g}) + 2 \text{O}_2 (\text{g}) \leftrightarrow \text{CO}_2 (\text{g}) + 2 \text{H}_2\text{O} (\text{g})$ Answer: The amount of $\text{CH}_3\text{OH}$ <b>increases</b> , because this combustion reaction releases heat; therefore, it goes in reverse to consume heat.	Addition of heat	$\text{CH}_3\text{OH}$
3.	$\text{CH}_3\text{OH} (\text{g}) + \text{H}_2 (\text{g}) \leftrightarrow \text{CH}_4 (\text{g}) + \text{H}_2\text{O} (\text{l})$ Answer: The amount of $\text{CH}_3\text{OH}$ <b>decreases</b> , because the reaction shifts to the right to decrease the pressure in the system; remember that liquids don't contribute to pressure.	Addition of pressure	$\text{CH}_3\text{OH}$
4.	$\text{N}_2 (\text{g}) + \text{O}_2 (\text{g}) \leftrightarrow 2 \text{NO} (\text{g})$ Answer: The amount of $\text{O}_2$ <b>does not change</b> , because the reaction cannot shift to increase the pressure in the system (there are equal amounts of gas on each side).	Reduction of pressure	$\text{O}_2$

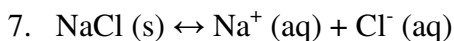
Give the equation for  $K_c$  for the equations given in problems 5-8.



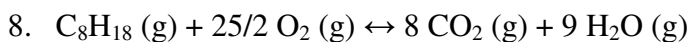
Answer:  $K_c = \frac{[\text{H}_2\text{O}]^2}{[\text{H}_2]^2[\text{O}_2]^2}$



Answer:  $K_c = \frac{[\text{H}_3\text{O}^+][\text{Cl}^-]}{[\text{HCl}]}$

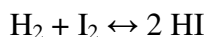


Answer:  $K_c = [\text{Na}^+][\text{Cl}^-]$  (This is known as  $K_{sp}$ , the solubility product for NaCl.)



Answer:  $K_c = \frac{[\text{CO}_2]^8[\text{H}_2\text{O}]^9}{[\text{C}_8\text{H}_{18}]^2[\text{O}_2]^{25/2}}$

9. Consider the following reaction at 25°C:



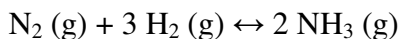
The reaction mixture is initially prepared with  $C_{\text{H}_2} = 0.1$ ,  $C_{\text{I}_2} = 0.1$ ,  $C_{\text{HI}} = 0.5$ . What is Q for this initial reaction mixture?

Answer:  $Q = C_{\text{HI}}^2 / C_{\text{H}_2} C_{\text{I}_2} = (0.5)^2 / (0.1 \cdot 0.1) = \underline{25}$

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

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

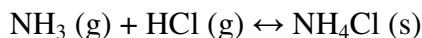
11. For the reaction



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

12. For the reaction



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

Answer:

At 300 K:  $\Delta G = -176 \text{ kJ/mol} - (300 \text{ K})(-305 \text{ J/mol K}) = -84.5 \text{ kJ}$   
 $K = \exp(-\Delta G/RT) = \exp[-(-84500 \text{ J/mol}) / (8.314 \text{ J/mol K} \cdot 300 \text{ K})]$

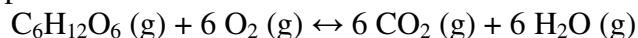
$$K = 5.17 \cdot 10^{14}$$

At 600 K: Similar calculations yield  $K = \underline{0.246}$

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

Answer:  $\Delta G = -RT \ln K = -(8.314 \text{ J/mol K})(298 \text{ K}) \ln(3.8) = \underline{-3.308 \text{ kJ/mol}}$

14. Assume that at some temperature, the reaction given below has an equilibrium constant  $K_p$  of 7.5.  $\text{C}_6\text{H}_{12}\text{O}_6$ ,  $\text{O}_2$ ,  $\text{CO}_2$ , and  $\text{H}_2\text{O}$  are placed in a reaction vessel, each with an initial concentration of 1 atm. What are the equilibrium pressures?



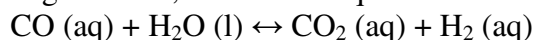
- a.  $P_{\text{C}_6\text{H}_{12}\text{O}_6} = 1.017$ ,  $P_{\text{O}_2} = 1.108$ ,  $P_{\text{CO}_2} = 0.892$ ,  $P_{\text{H}_2\text{O}} = 0.891$   
 b.  $P_{\text{C}_6\text{H}_{12}\text{O}_6} = 0.898$ ,  $P_{\text{O}_2} = 0.387$ ,  $P_{\text{CO}_2} = 1.613$ ,  $P_{\text{H}_2\text{O}} = 1.613$   
**c.  $P_{\text{C}_6\text{H}_{12}\text{O}_6} = 0.981$ ,  $P_{\text{O}_2} = 0.887$ ,  $P_{\text{CO}_2} = 1.112$ ,  $P_{\text{H}_2\text{O}} = 1.112$**   
 d.  $P_{\text{C}_6\text{H}_{12}\text{O}_6} = 1.465$ ,  $P_{\text{O}_2} = 1.465$ ,  $P_{\text{CO}_2} = 0.535$ ,  $P_{\text{H}_2\text{O}} = 0.535$

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  $\text{C}_6\text{H}_{12}\text{O}_6$ .

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

16. Assume that the reaction below has an equilibrium constant of 105 at some temperature. If you start out with 1 M  $\text{CO}_2$  and 1 M  $\text{H}_2$  in 3 kg of water, what is the equilibrium concentration of  $\text{CO}$ ?



Answer:

CO (aq)	H <sub>2</sub> O (l)	CO <sub>2</sub> (aq)	H <sub>2</sub> (aq)
0	XXXXXX	1	1
+x	XXXXXX	-x	-x
x	XXXXXX	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  $x = 107$ ,  $[\text{CO}_2]$  and  $[\text{H}_2]$  would be negative, so  **$[\text{CO}] = x = \underline{0.00935 \text{ M}}$** .

17. For the same reaction as in number 14, imagine you have some mixture of  $\text{CO}$ ,  $\text{CO}_2$ , and  $\text{H}_2$  in water. You know that initially  $C_{\text{CO}} = 0.0025 \text{ M}$  and  $C_{\text{H}_2} = 0.5 \text{ M}$ . The equilibrium concentration of  $\text{CO}_2$  ends up being 0.005. What are the initial and final concentrations of  $\text{CO}_2$  in this reaction?

Answer:

CO (aq)	H <sub>2</sub> O (l)	CO <sub>2</sub> (aq)	H <sub>2</sub> (aq)
0.0025	XXXXXX	x	0.5
+0.0025	XXXXXX	-0.0025	-0.0025
0.005	XXXXXX	x-0.0025	0.4975

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

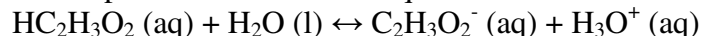
$$0.525 = 0.4975x - 0.00124375$$

$$x = 1.05778$$

So  **$\underline{\text{initial } C_{\text{CO}_2} = 1.05778 \text{ M, final } [\text{CO}_2] = 1.05528 \text{ M}}$**

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  $1.8 \times 10^{-5}$ . Given that the pH of a solution is defined by

$\text{pH} = -\log_{10}([\text{H}_3\text{O}^+])$ , what is the pH of this solution at equilibrium?



Answer:

$\text{HC}_2\text{H}_3\text{O}_2$ (aq)	$\text{H}_2\text{O}$ (l)	$\text{C}_2\text{H}_3\text{O}_2^-$ (aq)	$\text{H}_3\text{O}^+$ (aq)
1	XXXXX	0	0
-x	XXXXX	+x	+x
1-x	XXXXX	x	x

$$K = 1.8 \times 10^{-5} = x^2/(1-x)$$

$$(1.8 \times 10^{-5}) - (1.8 \times 10^{-5})x = x^2$$

$$x^2 + (1.8 \times 10^{-5})x - (1.8 \times 10^{-5}) = 0$$

$$x = 0.00423 \text{ M}$$

$$\text{pH} = -\log_{10}([\text{H}_3\text{O}^+]) = -\log_{10}(x) = -\log_{10}(0.00423) = \underline{\underline{2.37}}$$

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

Answer:

A	$\text{A}^*$
1	1
-x	+x
1-x	1+x

$$K = 1.5 = (1+x)/(1-x)$$

$$1.5 - 1.5x = 1 + x$$

$$.5 = 2.5 x$$

$$x = 0.2$$

$$\underline{\underline{[\text{A}^*] = 1 + 0.2 = 1.2 \text{ M}}}$$

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

Answer:

A	$\text{A}^*$
0.8	0.12
-x	+x
0.8-x	0.12+x

$$K = 1.5 = (0.12+x)/(0.8-x)$$

$$1.2 - 1.5x = 0.12 + x$$

$$1.08 = 2.5 x$$

$$x = 0.432$$

$$\underline{\underline{[\text{A}^*] = 0.12 + 0.432 = 0.552 \text{ M}}}$$