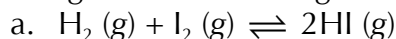


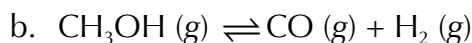
Name _____ Section _____

Worksheet 7: Chemical Equilibrium and Acids/Bases

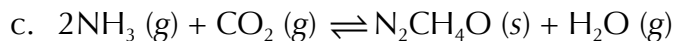
1. For each of the following reactions, write the expressions for K_c and K_p . What is the relationship between K_c and K_p ? Does the reaction represent a homogeneous or heterogeneous equilibrium?



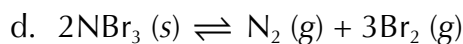
$$K_c = \frac{[\text{HI}]^2}{[\text{H}_2][\text{I}_2]} \quad K_p = \frac{(P_{\text{HI}})^2}{P_{\text{H}_2}P_{\text{I}_2}} \quad K_c = K_p \quad \text{homogeneous}$$



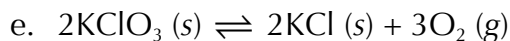
$$K_c = \frac{[\text{H}_2][\text{CO}]}{[\text{CH}_3\text{OH}]} \quad K_p = \frac{P_{\text{H}_2}P_{\text{CO}}}{P_{\text{CH}_3\text{OH}}} \quad K_c(RT) = K_p \quad \text{homogeneous}$$



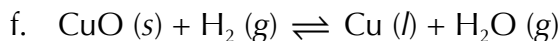
$$K_c = \frac{[\text{H}_2\text{O}]}{[\text{NH}_3]^2[\text{CO}_2]} \quad K_p = \frac{P_{\text{H}_2\text{O}}}{(P_{\text{NH}_3})^2 P_{\text{CO}_2}} \quad K_c(RT)^{-2} = K_p \quad \text{heterogeneous}$$



$$K_c = [\text{Br}_2]^3 [\text{N}_2] \quad K_p = (P_{\text{Br}_2})^3 P_{\text{N}_2} \quad K_c(RT)^4 = K_p \quad \text{heterogeneous}$$

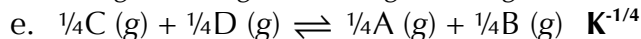
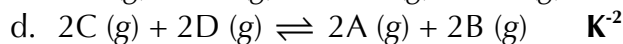
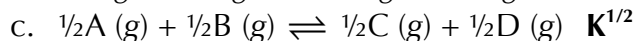
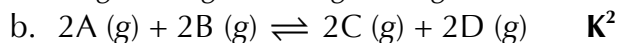


$$K_c = [\text{O}_2]^3 \quad K_p = (P_{\text{O}_2})^3 \quad K_c(RT)^3 = K_p \quad \text{heterogeneous}$$

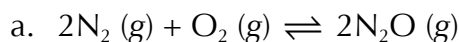


$$K_c = \frac{[\text{H}_2\text{O}]}{[\text{H}_2]} \quad K_p = \frac{P_{\text{H}_2\text{O}}}{P_{\text{H}_2}} \quad K_c = K_p \quad \text{heterogeneous}$$

2. The equilibrium constant for the reaction $\text{A}(\text{g}) + \text{B}(\text{g}) \rightleftharpoons \text{C}(\text{g}) + \text{D}(\text{g})$ is K . What is the equilibrium constant for each of the following reactions?



3. For the following reactions calculate K using the given equilibrium conditions. Do the second set of conditions represent a system at equilibrium? If not, which way will the reaction shift in order to reach equilibrium?



- i. 2.80×10^{-4} mol N_2 , 2.50×10^{-5} mol O_2 , 2.00×10^{-2} mol N_2O in a 2.00 L flask

$$[\text{N}_2\text{O}] = \frac{2.00 \times 10^{-2} \text{ mol}}{2.00 \text{ L}} = 1.00 \times 10^{-2} \text{ M}$$

$$[\text{N}_2] = \frac{2.80 \times 10^{-4} \text{ mol}}{2.00 \text{ L}} = 1.40 \times 10^{-4} \text{ M}$$

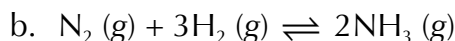
$$[\text{O}_2] = \frac{2.50 \times 10^{-5} \text{ mol}}{2.00 \text{ L}} = 1.25 \times 10^{-5} \text{ M}$$

$$K_c = \frac{[\text{N}_2\text{O}]^2}{[\text{N}_2]^2 [\text{O}_2]} = \frac{(1.00 \times 10^{-2})^2}{(1.40 \times 10^{-4})^2 (1.25 \times 10^{-5})} = 4.08 \times 10^8$$

- ii. $[\text{N}_2] = 2.00 \times 10^{-4} \text{ M}$, $[\text{O}_2] = 0.00245 \text{ M}$, $[\text{N}_2\text{O}] = 0.200 \text{ M}$

$$Q_c = \frac{[\text{N}_2\text{O}]^2}{[\text{N}_2]^2 [\text{O}_2]} = \frac{(0.200)^2}{(2.00 \times 10^{-4})^2 (0.00245)} = 4.08 \times 10^8$$

at equilibrium



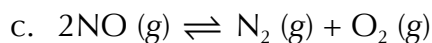
- i. $P_{\text{NH}_3} = 3.1 \times 10^{-2} \text{ atm}$, $P_{\text{N}_2} = 8.5 \times 10^{-1} \text{ atm}$, $P_{\text{H}_2} = 3.1 \times 10^{-3} \text{ atm}$

$$K_p = \frac{(P_{\text{NH}_3})^2}{P_{\text{N}_2} (P_{\text{H}_2})^3} = \frac{(3.1 \times 10^{-2})^2}{(0.85)(3.1 \times 10^{-3})^3} = 3.8 \times 10^4$$

- ii. $P_{\text{N}_2} = 0.525 \text{ atm}$, $P_{\text{NH}_3} = 0.0167 \text{ atm}$, $P_{\text{H}_2} = 0.00761 \text{ atm}$

$$Q_p = \frac{(P_{\text{NH}_3})^2}{P_{\text{N}_2} (P_{\text{H}_2})^3} = \frac{(0.0167)^2}{(0.525)(0.00761)^3} = 1.21 \times 10^3$$

shift to right (products)



- i. 0.032 mol NO, 0.62 mol N_2 , and 4.0 mol O_2 in a 2.0 L flask

$$[\text{NO}] = \frac{0.032 \text{ mol}}{2.0 \text{ L}} = 0.016 \text{ M}$$

$$[\text{N}_2] = \frac{0.62 \text{ mol}}{2.0 \text{ L}} = 0.31 \text{ M}$$

$$[\text{O}_2] = \frac{4.0 \text{ mol}}{2.0 \text{ L}} = 2.0 \text{ M}$$

$$K_c = \frac{[\text{N}_2][\text{O}_2]}{[\text{NO}]^2} = \frac{(0.31)(2.0)}{(0.016)^2} = 2.4 \times 10^3$$

- ii. 0.024 mol NO, 2.0 mol N_2 , and 2.6 mol O_2 in a 1.0 L flask

$$[\text{NO}] = \frac{0.024 \text{ mol}}{1.0 \text{ L}} = 0.024 \text{ M}$$

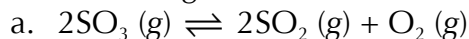
$$[\text{N}_2] = \frac{2.0 \text{ mol}}{1.0 \text{ L}} = 2.0 \text{ M}$$

$$[\text{O}_2] = \frac{2.6 \text{ mol}}{1.0 \text{ L}} = 2.6 \text{ M}$$

$$Q_c = \frac{[\text{N}_2][\text{O}_2]}{[\text{NO}]^2} = \frac{(2.0)(2.6)}{(0.024)^2} = 9.0 \times 10^3$$

shift to left (reactants)

4. For the following reactions and with the information given, calculate K.

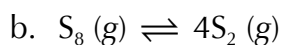


Initially 12.0 mol SO_3 is placed in a 3.0 L rigid container. At equilibrium, 3.0 mol SO_2 is present.

	$[\text{SO}_3]$	$[\text{SO}_2]$	$[\text{O}_2]$
Initial	4.0	0	0
Change	-2x	+2x	+x
Equilibrium	$4.0 - 2x = 3.0$	$2x = 1.0$	$x = 0.50$

Only reactants are present, so reaction must proceed to form products.

$$K_c = \frac{[\text{SO}_2]^2 [\text{O}_2]}{[\text{SO}_3]^2} = \frac{(1.0)^2 (0.50)}{(3.0)^2} = 0.056$$



Initially, a sample of S_8 is placed in an empty rigid container at a pressure of 1.00 atm. At equilibrium, the partial pressure of S_8 is 0.25 atm.

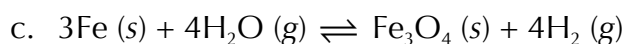
	P_{S_8}	P_{S_2}
Initial	1.00	0
Change	-x	+4x
Equilibrium	1.00-x	4x

Only reactants are present, so reaction must proceed to form products.

$$1.00\text{ atm} - x = 0.25\text{ atm} \rightarrow x = 0.75\text{ atm}$$

$$P_{S_2} = 4(0.75\text{ atm}) = 3.0\text{ atm}$$

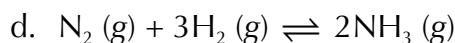
$$K_p = \frac{(P_{S_2})^4}{P_{S_8}} = \frac{(3.0)^4}{0.25} = 3.2 \times 10^2$$



When the equilibrium partial pressure of water vapor is 15.0 torr, the total pressure at equilibrium is 36.3 torr.

$$P_{total} = P_{H_2O} + P_{H_2}; \quad 36.3\text{ torr} = 15.0\text{ torr} + P_{H_2}; \quad P_{H_2} = 21.3\text{ torr}$$

$$K_p = \frac{(P_{H_2})^4}{(P_{H_2O})^4} = \frac{\left(21.3\text{ torr} \times \frac{1\text{ atm}}{760\text{ torr}}\right)^4}{\left(15.0\text{ torr} \times \frac{1\text{ atm}}{760\text{ torr}}\right)^4} = 4.07$$



In a closed container, 1.00 atm of N_2 is mixed with 2.00 atm of H_2 . At equilibrium, the total pressure is 2.00 atm

	P_{N_2}	P_{H_2}	P_{NH_3}
Initial	1.00	2.00	0
Change	-x	-3x	+2x
Equilibrium	1.00-x	2.00-3x	2x

Only reactants are present, so reaction must form products.

$$P_{total} = 2.00\text{ atm} = P_{N_2} + P_{H_2} + P_{NH_3} = (1.00 - x) + (2.00 - 3x) + (2x) \rightarrow x = 0.500\text{ atm}$$

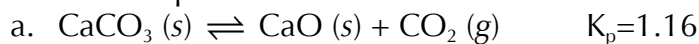
$$P_{N_2} = 1.00\text{ atm} - 0.500\text{ atm} = 0.500\text{ atm}$$

$$P_{H_2} = 2.00\text{ atm} - 3(0.500\text{ atm}) = 0.500\text{ atm}$$

$$P_{NH_3} = 2(0.500\text{ atm}) = 1.00\text{ atm}$$

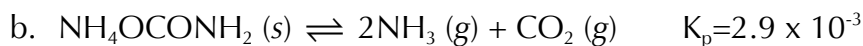
$$K_p = \frac{[NH_3]^2}{[N_2][H_2]^3} = \frac{(1.00)^2}{(0.500)(0.500)^3} = 16.0$$

5. For the following reactions and with the given initial conditions and K, calculate the equilibrium concentrations.



An evacuated 10.0 L container.

$$K_p = 1.16 \text{ atm} = P_{\text{CO}_2}$$



An evacuated rigid container.

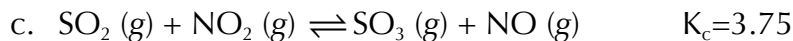
	$[\text{NH}_3]$	$[\text{CO}_2]$
Initial	0	0
Change	+2x	+x
Equilibrium	2x	x

Only reactants are present, so reaction must proceed to form products.

$$K_p = 2.9 \times 10^{-3} = (P_{\text{NH}_3})^2 P_{\text{CO}_2} = (2x)^2 x = 4x^3 \rightarrow x = 9.0 \times 10^{-2} \text{ atm}$$

$$P_{\text{NH}_3} = 2(9.0 \times 10^{-2} \text{ atm}) = 0.18 \text{ atm}$$

$$P_{\text{CO}_2} = 9.0 \times 10^{-2} \text{ atm}$$



All four gases have initial concentrations of 0.800 M

$$K_c = \frac{[\text{SO}_3][\text{NO}]}{[\text{SO}_2][\text{NO}_2]} \quad Q_c = \frac{[0.800][0.800]}{[0.800][0.800]} = 1.00 \quad \text{shift to right}$$

	$[\text{SO}_2]$	$[\text{NO}_2]$	$[\text{SO}_3]$	$[\text{NO}]$
Initial	0.800	0.800	0.800	0.800
Change	-x	-x	+x	+x
Equilibrium	0.800-x	0.800-x	0.800+x	0.800+x

$$K_c = \frac{[0.800+x][0.800+x]}{[0.800-x][0.800-x]} = \frac{[0.800+x]^2}{[0.800-x]^2} = 3.75$$

$$\frac{[0.800+x]}{[0.800-x]} = \sqrt{3.75} = 1.94 \rightarrow 0.800+x = 1.55 - 1.94x \rightarrow x = 0.26 \text{ M}$$

$$[\text{SO}_3] = [\text{NO}] = 0.800 + 0.26 = 1.06 \text{ M}$$

$$[\text{SO}_2] = [\text{NO}_2] = 0.800 - 0.26 = 0.54 \text{ M}$$

- d. $\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{NO}(\text{g})$ $K_c = 0.050$
Initially, $P_{\text{N}_2} = 0.80 \text{ atm}$, $P_{\text{O}_2} = 0.20 \text{ atm}$ and $P_{\text{NO}} = 0$.

	P_{N_2}	P_{O_2}	P_{NO}
Initial	0.80	0.20	0
Change	-x	-x	+2x
Equilibrium	$0.80 - x$	$0.20 - x$	2x

Only reactants are present, so reaction must proceed to form products.

$$K_c = K_p = \frac{(P_{\text{NO}})^2}{P_{\text{N}_2} P_{\text{O}_2}} = \frac{(2x)^2}{(0.80 - x)(0.20 - x)} = 0.050$$

$$3.95x^2 + 0.050x - 8.0 \times 10^{-3} = 0$$

solve with quadratic formula or graphing calculator

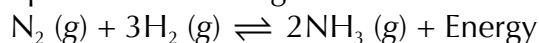
$$x = 3.9 \times 10^{-2} \text{ atm} \text{ only positive root}$$

$$P_{\text{N}_2} = 0.80 \text{ atm} - (3.9 \times 10^{-2} \text{ atm}) = 0.76 \text{ atm}$$

$$P_{\text{H}_2} = 0.20 \text{ atm} - (3.9 \times 10^{-2} \text{ atm}) = 0.16 \text{ atm}$$

$$P_{\text{NO}} = 2(3.9 \times 10^{-2} \text{ atm}) = 7.8 \times 10^{-2} \text{ atm}$$

6. Complete the following table for the reaction:



	$[\text{N}_2]$	$[\text{H}_2]$	$[\text{NH}_3]$
Remove N_2	-----	increases	decreases
Remove H_2	increases	-----	decreases
Remove NH_3	decreases	decreases	-----
Add N_2	-----	decreases	increases
Add H_2	decreases	-----	increases
Add NH_3	increases	increases	-----
Decrease temperature	decreases	decreases	increases
Increase temperature	increases	increases	decreases
Decrease pressure	increases	increases	decreases
Increase pressure	decreases	decreases	increases
Decrease volume	decreases	decreases	increases
Increase volume	increases	increases	decreases
Add catalyst	-----	-----	-----
Add 1 mol Ar (g)	-----	-----	-----

7. Classify each of the following substances as either a strong or weak base/acid. Identify its conjugate acid/base. For the strong acid/base solutions, calculate $[H^+]$, pH, $[OH^-]$, and pOH. $K_w = 1.0 \times 10^{-14}$

a. 0.250 M HNO_3 **strong acid** **conj. base = NO_3^-**

$$[H^+] = 0.250 M$$

$$pH = -\log(0.250) = 0.602$$

$$pOH = 14 - 0.602 = 13.398$$

$$[OH^-] = \frac{10^{-14}}{0.250} = 4.00 \times 10^{-14} M$$

b. 0.33 M NH_3 **weak base** **conj. acid = NH_4^+**

c. 0.40 M $HCOOH$ **weak acid** **conj. base = $HCOO^-$**

d. 0.50 M $HClO_4$ **strong acid** **conj. base = ClO_4^-**

$$[H^+] = 0.50 M$$

$$pH = -\log(0.50) = 0.30$$

$$pOH = 14 - 0.30 = 13.70$$

$$[OH^-] = \frac{10^{-14}}{0.50} = 2.0 \times 10^{-14} M$$

e. 0.1 M HF **weak acid** **conj. base = F^-**

f. 0.20 M HCl **strong acid** **conj. base = Cl^-**

$$[H^+] = 0.20 M$$

$$pH = -\log(0.20) = 0.70$$

$$pOH = 14 - 0.70 = 13.30$$

$$[OH^-] = \frac{10^{-14}}{0.20} = 5.0 \times 10^{-14} M$$

g. 2.2 M H_3PO_4 **weak acid** **conj. base = $H_2PO_4^-$**