Chemistry 122
Worksheet: Chemical Equilibrium

1. What is the percent yield if you experimentally produce 3.65 g of copper when 1.87 g of aluminum reacts with 9.65 g of copper (II) sulfate?

$$Al + CuSO_4 \leftrightarrow Cu + Al_2(SO_4)_3$$

2. Hydrogen peroxide is decomposed as follows:

$$H_2O_{2(l)} \leftrightarrow H_{2(g)} + O_{2(g)} \qquad \Delta H_r = +187 \text{ kJ}$$

Predict the direction of equilibrium shift by each of the following imposed changes:

a) Increase the $[H_2]$ .... Answer shift left
b) Decrease the $[O_2]$ .... Answer shift right
c) Decrease the total pressure.............................. Answer shift right
d) Increase the temperature................................. Answer shift right
e) Add MnO_2 as a catalyst................................. Answer no change

3. Zinc and sulfur react to produce zinc sulfide, according to the following reaction.

$$Zn_{(s)} + S_{(s)} \leftrightarrow ZnS_{(s)}$$

If 25.0 g of zinc, and 30.0 g of sulfur are mixed, 12.8 g of zinc sulfide is found at equilibrium. Determine the limiting reagent, and calculate the percent yield.

4. For the equilibrium listed below, list four stresses that could be placed on the system in an attempt to maximize the amount of product formed.

$$2H_{2(g)} + O_{2(g)} \leftrightarrow 2H_2O_{(g)} \qquad \Delta H_r = -483.6 \text{ kJ}$$

5. Consider the following reaction:

$$CO_{2(g)} + H_{2(g)} \leftrightarrow CO_{(g)} + H_2O_{(g)}$$

Calculate the value of the equilibrium constant, K, for the above system, if 0.1908 moles of CO_2, 0.0908 moles of H_2, 0.0092 moles of CO, and 0.0092 moles of H_2O vapour were present in a 2.00 L reaction vessel at equilibrium.

6. K for $H_2 + I_2 \Longleftrightarrow 2HI$ is 32.0. At equilibrium, $[H_2] = 0.400$ and $[I_2] = 0.0500$. What does [HI] equal?

These three problems are meant to be challenging. Give them a try!

7. Aluminum dissolves in an aqueous solution of NaOH according to the following reaction:

$$2NaOH + 2Al + 2H_2O \leftrightarrow 2NaAlO_2 + 3H_2$$

If 84.1 g of NaOH and 51.0 g of Al react:
i) Which is the limiting reagent?
ii) How much of the other reagent remains?
iii) What mass of hydrogen is produced

8. A research supervisor told a chemist to make 100.0 g of chlorobenzene from the reaction of benzene and chlorine, and to expect a yield no higher than 65%. What is the minimum quantity of benzene that can give 100.0g of chorobenzene if the yield is 65%? The equation for the reaction is:

$$C_6H_6 + Cl_2 \leftrightarrow C_6H_5Cl + HCl$$

9. Adipic acid, $C_6H_{10}O_4$, is a raw material for the making of nylon and it can be prepared in the laboratory by the following reaction between cyclohexene, C_6H_{10}, and sodium dichromate, $Na_2Cr_2O_7$ in sulphuric acid.

$$3C_6H_{10}O_{4(l)} + 4Na_2Cr_2O_{7(aq)} + 16H_2SO_{4(aq)} \leftrightarrow 3C_6H_{10}O_{4(aq)} + 4Cr_2(SO_4)_{3(aq)} + 4Na_2SO_{4(aq)} + 16H_2O_{(l)}$$

There are side reactions. These plus losses of product during its purification reduce the overall yield. A typical yield of purified adipic acid is 68.6%.

(a) To prepare 12.5 grams of adipic acid in 68.6% yield requires how many grams of cyclohexene?

(b) The only available supply of sodium dichromate is its dihydrate, $Na_2Cr_2O_7 \cdot 2H_2O$. Since the reaction occurs in an aqueous medium, the water in the dihydrate causes no problems, but it does contribute to the mass of what is taken of this reactant! How many grams of this dihydrate are also required in the preparation of 12.5 grams of adipic acid in a yield of 68.6%?

WORKSHEET: CHEMICAL EQUILIBRIUM

#1. $2Al_{(s)} + 3CuSO_{4(aq)} \longleftrightarrow 3Cu_{(s)} + Al_2(SO_4)_{3(aq)}$

init. 1.87g   9.65g   3.65g ↓ eqm.

If Al is L.R.

$1.87\,g\ Al \times \frac{1\ mol\ Al}{26.98\,g\ Al} \times \frac{3\ mol\ Cu}{2\ mol\ Al} \times \frac{63.54\,g\ Cu}{1\ mol\ Cu} = 6.61\,g\ Cu$

If $CuSO_4$ is L.R.

$9.65\,g\ CuSO_4 \times \frac{1\ mol\ CuSO_4}{159.60\,g\ CuSO_4} \times \frac{3\ mol\ Cu}{3\ mol\ CuSO_4} \times \frac{63.54\,g\ Cu}{1\ mol\ Cu} = 3.84\,g\ Cu$

∴ $CuSO_4$ is L.R.

$\%\ yield = \frac{exp}{theor.} \times 100\%$

$\%\ yield = \frac{3.65\,g}{3.84\,g} \times 100\%$

% yield = 95.1%

#3. $Zn_{(s)} + S_{(s)} \rightleftharpoons ZnS_{(s)}$

25.0g   30.0g   12.8g

If Zn is L.R.

$25.0\,g\ Zn \times \frac{1\ mol\ Zn}{65.39\,g\ Zn} \times \frac{1\ mol\ ZnS}{1\ mol\ Zn} \times \frac{97.45\,g\ ZnS}{1\ mol\ ZnS} = 37.26\,g\ ZnS$

If S is L.R.

$30.0\,g\ S \times \frac{1\ mol\ S}{32.06\,g\ S} \times \frac{1\ mol\ ZnS}{1\ mol\ S} \times \frac{97.45\,g\ ZnS}{1\ mol\ ZnS} = 91.19\,g\ ZnS$

∴ Zn is L.R.

$\%\ yield = \frac{exp}{theor} \times 100\%$

$\%\ yield = \frac{12.8\,g}{37.26\,g} \times 100\%$

% yield = 34.4%

4. $2H_{2(g)} + O_{2(g)} \rightleftharpoons 2H_2O_{(g)}$ $\Delta H_r = -483.6\ kJ$

① Increase $[H_{2(g)}]$, $[O_{2(g)}]$
② Cool system
③ Decrease $[H_2O_{(g)}]$
④ Increase pressure
⑤ Decrease volume

5. $CO_{2(g)} + H_{2(g)} \rightleftharpoons CO_{(g)} + H_2O_{(g)}$ $V = 2.00L$

	$CO_{2(g)}$	$H_{2(g)}$	$CO_{(g)}$	$H_2O_{(g)}$
eqm.	0.1908 mol	0.0908 mol	0.0092 mol	0.0092 mol
[ ]	0.0954 M	0.0454 M	0.0046 M	0.0046 M

$$K = \frac{[CO_{(g)}][H_2O]}{[CO_{2(g)}][H_{2(g)}]}$$

$$K = \frac{[0.0046][0.0046]}{[0.0954\ M][0.0454\ M]}$$

$$\boxed{K = 4.89 \times 10^{-3}}$$

6. $H_{2(g)} + I_{2(g)} \rightleftharpoons 2HI_{(g)}$

eqm. 0.400M 0.0500M

$$K = \frac{[HI_{(g)}]^2}{[H_{2(g)}][I_{2(g)}]} = 32.0$$

$$[HI_{(g)}] = \sqrt{32.0\,[0.400M][0.0500M]}$$

$$\boxed{[HI_{(g)}] = 0.800M}$$

#7. $2NaOH + 2Al + 2H_2O \rightleftharpoons 2NaAlO_2 + 3H_2$

init. 84.1g 51.0g

i) If NaOH is L.R.

$$84.1\text{g NaOH} \times \frac{1\text{ mol NaOH}}{40.00\text{g NaOH}} \times \frac{3\text{ mol } H_2}{2\text{ mol NaOH}} \times \frac{2.02\text{g } H_2}{1\text{ mol } H_2} = 6.37\text{g } H_2$$

If Al is L.R.

$$51.0\text{g Al} \times \frac{1\text{ mol Al}}{26.98\text{g Al}} \times \frac{3\text{ mol } H_2}{2\text{ mol Al}} \times \frac{2.02\text{g } H_2}{1\text{ mol } H_2} = 5.73\text{g } H_2$$

∴ Al is L.R.

ii) $$51.0\text{g Al} \times \frac{1\text{ mol Al}}{26.98\text{g Al}} \times \frac{2\text{ mol NaOH}}{2\text{ mol Al}} \times \frac{40.00\text{g NaOH}}{1\text{ mol NaOH}} = 75.6\text{g NaOH used}$$

Amount xs reagent: 84.1g − 75.6g = 8.5g NaOH

iii) 5.73g H_2 produced.

#8. $C_6H_6 + Cl_2 \rightleftharpoons C_6H_5Cl + HCl$

100.0g (C_6H_5Cl)

$$\%\text{yield} = \frac{\text{exp}}{\text{theor}} \times 100\%$$

$$0.65 = \frac{100.0\text{g}}{\text{theor.}}$$

$$\text{theor. yield} = \frac{100.0\text{g}}{0.65} = 153.85\text{g}$$

$$153.85\text{g } C_6H_5Cl \times \frac{1\text{ mol } C_6H_5Cl}{112.56\text{g } C_6H_5Cl} \times \frac{1\text{ mol } C_6H_6}{1\text{ mol } C_6H_5Cl} \times \frac{78.12\text{g } C_6H_6}{1\text{ mol } C_6H_6} = 106.8\text{g}$$

9. $3C_6H_{10(l)} + 4Na_2Cr_2O_{7(aq)} + 16H_2SO_{4(aq)} \rightleftharpoons 3C_6H_{10}O_{4(aq)} + 4Cr_2(SO_4)_{3(aq)} + 4Na_2SO_{4(aq)} + 16H_2O_{(l)}$

eqm. 12.5g

% yield = 68.6%

$$\% \text{ yield} = \frac{\text{exp}}{\text{theor.}} \times 100\%$$

$$\text{theor. yield} = \frac{12.5\text{g}}{0.686}$$

theor. yield = 18.22g

$$18.22\text{g } C_6H_{10}O_4 \times \frac{1 \text{ mol } C_6H_{10}O_4}{146.16\text{g } C_6H_{10}O_4} \times \frac{3 \text{ mol } C_6H_{10}}{3 \text{ mol } C_6H_{10}O_4} \times \frac{82.16\text{g } C_6H_{10}}{1 \text{ mol } C_6H_{10}} = \boxed{10.2\text{g } C_6H_{10}}$$

b) $$18.22\text{g } C_6H_{10}O_4 \times \frac{1 \text{ mol } C_6H_{10}O_4}{146.16\text{g } C_6H_{10}O_4} \times \frac{4 \text{ mol } Na_2Cr_2O_{7(aq)} \cdot 2H_2O}{3 \text{ mol } C_6H_{10}O_4} \times \frac{298.02\text{g } Na_2Cr_2O_{7(aq)} \cdot 2H_2O}{1 \text{ mol } Na_2Cr_2O_7 \cdot 2H_2O}$$

$$= \boxed{49.5\text{g } Na_2Cr_2O_7 \cdot 2H_2O}$$