## Chapter 9- Lecture Worksheet 4

1. Summarize the ICE Method
2. Write the Balanced Chemical Equation. (always start with this for any equilibrium calculation !)
3. Write the Initial Concentrations under each substance. (may be in units of $M$, or partial pressures for gases)
4. Write the Change in Concentrations in terms of x . (moles/L of reactant lost)
5. Write the Equilibrium Concentrations in terms of initial concs and x .
6. Put into $K$ expression. (equation relating $K$ to equilibrium concentrations)
7. Calulate $\boldsymbol{K}$ or Solve for $\boldsymbol{x}$. (Depends on what you are looking for. Is your answer physically reasonable ?)
8. Check !! (Check approximation or exact calculation.)
9. The equilibrium constant, $\mathrm{K}_{\mathrm{c}}$ for the following reaction is $5.9 \times 10^{-3}$ at $25^{\circ} \mathrm{C}$.

Suppose 0.34 moles of $\mathrm{N}_{2} \mathrm{O}_{4}(\mathrm{~g})$ are placed in a 1.00 L flask. What is the equilibrium concentration of $\mathrm{NO}_{2}(\mathrm{~g})$ ? You must use the ICE method to solve this problem.

|  | $\mathbf{N}_{\mathbf{2}} \mathbf{O}_{\mathbf{4}}(\mathbf{g})$ | $\rightleftharpoons$ | $\mathbf{2} \mathbf{N O}_{\mathbf{2}}(\mathbf{g})$ |
| :---: | :---: | :---: | :---: |
| Initial | 0.34 M |  | 0 |
| Change | $-\frac{\mathrm{x}}{4}$ |  | $\frac{+2 \mathrm{x}}{2 \mathrm{x}}$ |
| Equilibrium | $0.34-\mathrm{x}$ |  | 2 l |

$$
K_{c}=\frac{\left[\mathrm{NO}_{2}(g)\right]^{2}}{\left[\mathrm{~N}_{2} \mathrm{O}_{4}(g)\right]}=\frac{(2 x)^{2}}{(0.34-x)}=5.9 \times 10^{-3}
$$

This is a quadratic equation.
Put into form $\mathrm{ax}^{2}+\mathrm{bx}+\mathrm{c}=0$
$4 \mathrm{x}^{2}+\mathrm{K}_{\mathrm{c}} \mathrm{x}-\mathrm{K}_{\mathrm{c}}(0.34)=0$

$=\frac{-\left(5.9 \times 10^{-3}\right) \pm \sqrt{\left(5.9 \times 10^{-3}\right)^{2}+(16)\left(5.9 \times 10^{-3}\right)(0.34)}}{8}$

$$
\begin{gathered}
\mathrm{x}=-2.12 \times 10^{-2} \text { (phycically unreasonable) or }+2.17 \times 10^{-2} \mathrm{M}(\text { correct answer }) \\
{\left[\mathrm{NO}_{2}\right]=2 \mathrm{x}=0.0434=0.043 \mathrm{M}}
\end{gathered}
$$

Check (use 3 sig figs):

$$
\frac{(2 x)^{2}}{(0.34-x)}=\frac{(0.0434)^{2}}{(0.34-0.0217)}=0.0059 \text { to two significant figures. Check ! }
$$

3. The principle industrial source of hydrogen gas is from natural gas and water via a two step process:
4. Reforming Reaction: $\mathrm{CH}_{4}(\mathrm{~g})+\mathrm{H}_{2} \mathrm{O}(\mathrm{g}) \rightleftharpoons \mathrm{CO}(\mathrm{g})+3 \mathrm{H}_{2}(\mathrm{~g})$
5. Shift reactions: $\quad \mathbf{C O}(\mathrm{g})+\mathbf{H}_{2} \mathrm{O}(\mathrm{g}) \rightleftharpoons \mathrm{CO}_{2}(\mathrm{~g})+\mathrm{H}_{2}(\mathrm{~g})$


The equilibrium constant, $\mathrm{K}_{\mathrm{p}}$ for the first reaction is $1.8 \times 10^{-7}$ at 600 K . Suppose 1.40 atm of $\mathrm{CH}_{4}(\mathrm{~g})$ and 2.30 atm of $\mathrm{H}_{2} \mathrm{O}(\mathrm{g})$ are placed in a reaction chamber. What will the equilibrium partial pressure of $\mathrm{H}_{2}(\mathrm{~g})$ be after the first reaction?

You must use the ICE method to solve this problem.

|  | $\mathbf{C H}_{\mathbf{4}}(\mathbf{g})$ | $+\mathbf{H}_{\mathbf{2}} \mathbf{O}(\mathbf{g})$ | $\rightleftharpoons$ | $\mathbf{C O}(\mathbf{g})$ | $+\mathbf{3 H}_{\mathbf{2}}(\mathbf{g})$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Initial | 1.40 atm | 2.30 atm |  | 0 | 0 |
| Change | $\frac{-\mathrm{x}}{}$ | $\frac{-\mathrm{x}}{0}$ |  | $\frac{+\mathrm{x}}{}$ | $\frac{+3 \mathrm{x}}{3}$ |
| Equilibrium | $1.40-\mathrm{x}$ | $2.30-\mathrm{x}$ |  | x | 3 x |

$$
K_{p}=\frac{P_{C O} P_{H_{2}}{ }^{3}}{P_{C H_{4}} P_{H_{2} \mathrm{O}}}=\frac{x(3 x)^{3}}{(1.40-x)(2.30-x)}=\frac{27 x^{4}}{(1.40-x)(2.30-x)}=1.8 \times 10^{-7}
$$

This is a QUARTIC equation. Can't put into simple form to solve.

## APPROXIMATE

$\mathrm{K}_{\mathrm{p}} \ll 1$ Reactant favored. Therefore x is SMALL
BIG NUMBER - SMALL nUMBER $\approx$ BIG NUMBER
Kp expression simplifies

$$
\begin{gathered}
K_{p}=1.8 \times 10^{-7} \approx \frac{27 x^{4}}{(1.40)(2.30)} \\
x=\sqrt[4]{\frac{(1.40)(2.30) K_{p}}{27}}=\sqrt[4]{2.15 \times 10^{-8}}=1.21 \times 10^{-2}=1.2 \times 10^{-2} \mathrm{~atm}
\end{gathered}
$$

## CHECK

Substitute in x , see if get correct $\mathrm{K}_{\mathrm{p}}$

$$
\frac{27\left(1.21 \times 10^{-2}\right)^{4}}{\left(1.40-1.21 \times 10^{-2}\right)\left(2.30-1.21 \times 10^{-2}\right)}=1.8 \times 10^{-7}
$$

Not Bad for an approximate answer. Sure simpifies the mathematics !!!
We will use this technique frequently for Acid/Base calculations.

