**Name ____________________________Chem 163 Section**: ______ **Team Number:** ______

# *ALE 9. Equilibrium Problems: ICE Practice!*

(Reference: 17.5 Silb*erberg 5th edition*)

**Equilibrium Calculations:** Show all work with correct significant figures. *Circle all numerical answers*.

**TYPE 1: THE EASIEST**—Plug the equilibrium concentrations directly into the $K_c$ *or* $K_p$ expression

1. At 250.°C equilibrium for the following system was established: $\mathbf{PCl_{5(g)} \rightleftharpoons PCl_{3(g)} + Cl_{2(g)}}$
Calculate the value of Kc at 250°C if analysis of the mixture at equilibrium showed that
$[PCl_{3(g)}] = 1.50 \times 10^{-2}$ mol/L; $[Cl_{2(g)}] = 1.50 \times 10^{-2}$ mol/L; $[PCl_{5(g)}] = 1.18$ mol/L

2. In the following equilibrium: $\mathbf{H_{2(g)} + I_{2(g)} \rightleftharpoons 2HI_{(g)}}$ at a particular temperature Kc = 54.1. The equilibrium concentrations of $H_2$ and HI were found to be as follows: $[H_{2(g)}] = 0.48 \times 10^{-3}$ mol/L and $[HI_{(g)}] = 3.53 \times 10^{-3}$ mol/L. What is the equilibrium concentration of $I_{2(g)}$ under these conditions?

**TYPE 2: HARDER—**Using initial concentrations of reactants and/or products)

3. In the following equilibrium: $\mathbf{H_{2(g)} + I_{2(g)} \rightleftharpoons 2HI_{(g)}}$ initial amounts of 20.57 moles of hydrogen and 5.22 moles of iodine were allowed to reach equilibrium at 450.°C in a closed container. At this point the mixture contained 10.22 moles of HI. Calculate $K_c$ at this temperature.

**TYPE 3a: HARDER STILL**—Using initial concentrations of reactants and/or products and the quadratic equation

4. In the following equilibrium ethanoic acid (acetic acid), $CH_3COOH_{(l)}$, reacts with ethanol to produce an ester plus water: $\mathbf{CH_3COOH_{(l)} + C_2H_5OH_{(l)} \rightleftharpoons CH_3CO_2C_2H_{5(l)} + H_2O_{(l)}}$ Suppose 8.0 mol of ethanoic acid and 6.0 mol of ethanol are placed in a 2.00 L vessel. What is the equilibrium amount of water produced (<u>in moles **and** grams</u>) if $K_c$ = 4.5 at the particular temperature of the reaction?

**TYPE 3b: HARDER STILL**—Using initial concentrations of reactants and/or products where volume does not cancel

5. Ethyl ethanoate ($CH_3CO_2C_2H_5$) can be formed by the reaction of ethene ($C_2H_4$) with ethanoic acid ($CH_3COOH$) in an inert solvent according to the equation $\mathbf{C_2H_4 + CH_3COOH \rightleftharpoons CH_3CO_2C_2H_5}$**.** In an experiment 0.50 moles of ethene was allowed to react with 0.20 moles of ethanoic acid at 10.$^o$C, the total volume being made up to 250. cm$^3$ with an inert solvent. When equilibrium had been established the mixture was found to contain 0.18 moles of ethyl ethanoate. Calculate the….
   - number of moles of ethene and ethanoic acid present at equilibrium,
   - molar concentration of each substance (reactants and product) present at equilibrium and the
   - value of $K_c$ for the reaction under these conditions.

**TYPE 4: EVEN HARDER STILL**—Using initial concentrations and quadratics where reacting ratio is NOT 1:1

6. In the following equilibrium: $\mathbf{2HI_{(g)} \rightleftharpoons H_{2(g)} + I_{2(g)}}$ Initial amounts of 1.0 mol of iodine and 2.0 moles of hydrogen were allowed to reach equilibrium at 440.°C. Calculate the equilibrium concentrations of all the substances present at this temperature given that $K_c$ = 0.020 at 440.°C.

**Let's make life simpler**: Assume the concentration of a reactant remains constant when $K_{eq}$ is small and the initial [reactant] is large. Use the 5% rule: see "Simplifying Assumption for Finding an Unknown Quantity" on page 757 , *Silberberg 5th ed*.

7. In a study of halogen bond strengths, 0.50 mol of $I_2$ was heated in a 2.5 liter vessel and the following reaction occurred: $\mathbf{I_{2(g)} \rightleftharpoons 2\ I_{(g)}}$.
   a.) Calculate [$I_2$] and [I] at equilibrium at 600. Kelvin; $K_c = 2.94 \times 10^{-10}$

   b.) Calculate [$I_2$] and [I] at equilibrium at 2000. K; $K_c$ = 0.209

**TYPE 5: ALMOST the HARDEST**—Combining initial concentrations with ratios that are NOT 1:1 and the use of grams rather than moles

8. In the equilibrium reaction: $\mathbf{Br_{2(g)} + Cl_{2(g)} \rightleftharpoons 2BrCl_{(g)}}$ it is found that after starting with 2.0 mols of $Br_{2(g)}$ and 4.0 mols of $Cl_{2(g)}$ the equilibrium mixture contained 82.36g of bromine. Calculate $K_c$ under these conditions.

**TYPE 6: THE HARDEST**—Predicting reaction direction and calculating equilibrium concentrations using initial concentrations and quadratics

9. An inorganic chemist studying the reactions of phosphorus halides mixes 0.1050 mol of $PCl_5$ with 0.0450 mol of $Cl_2$ and 0.0450 mol of $PCl_3$ in a 0.5000 liter flask at 250. $^oC$: $\mathbf{PCl_{5(g)} \rightleftharpoons PCl_{3(g)} + Cl_{2(g)}}$; $K_c = 4.2 \times 10^{-2}$
   a.) In which direction will the reaction proceed? Show work/explain.

   b.) If $[PCl_5] = 0.2065\ M$ at equilibrium, what are the equilibrium concentrations of the other components?

## Application Questions

10. The synthesis of ammonia gas, $NH_3$, is one of the world's most important industrial reactions since ammonia is the starting material for the industrial production of nitrogen containing fertilizers. There would be mass worldwide starvation without the following all-important reaction that uses atmospheric nitrogen and hydrogen derived from fossil fuels such as methane gas, $CH_4$:

$$\mathbf{N_{2(g)} + 3\ H_{2(g)} \rightleftharpoons 2\ NH_{3(g)} \quad \Delta H^{\circ}_{rxn} = -91.8\ kJ}$$

a.) You are a member of a research team of chemists who are discussing plans to operate an ammonia processing plant. The plant operates at close to 700. K, at which $K_p$ is 1.00 x $10^{-4}$, and employs and maintains the stoichiometric ratio of 1 mol $N_2$ : 3 mol $H_2$. At equilibrium the partial pressure of ammonia is 50. atm. Calculate the partial pressures of each reactant and the total pressure under these operating conditions.

b.) One member of your team makes the following suggestion: since the partial pressure of $H_2$ is cubed in the reaction quotient, the plant could produce the same amount of ammonia if the reactants were in a ratio of 1 mol $N_2$ : 6 mol $H_2$ and could do so at a lower pressure, which would lower operating costs and, thus, increase profitability. Calculate the partial pressure of each reactant and the total pressure under these operating conditions, assuming an unchanged partial pressure for ammonia, 50. atm. Is the team member's argument valid?

c.) Discuss the advantages and disadvantages of carrying the reaction out at high temperatures.

d.) If a catalyst were employed to speed up the production of ammonia, how would the catalyst effect the position of equilibrium? *Explain*.