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

(Reference: 17.5 Silberberg 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 250.0°C equilibrium for the following system was established: \( \text{PCl}_5(g) \rightleftharpoons \text{PCl}_3(g) + \text{Cl}_2(g) \)
   Calculate the value of $K_c$ at 250°C if analysis of the mixture at equilibrium showed that
   \[
   [\text{PCl}_3(g)] = 1.50 \times 10^{-2} \text{ mol/L}; \quad [\text{Cl}_2(g)] = 1.50 \times 10^{-2} \text{ mol/L}; \quad [\text{PCl}_5(g)] = 1.18 \text{ mol/L}
   \]

2. In the following equilibrium: \( \text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2\text{HI}(g) \) at a particular temperature $K_c = 54.1$. The equilibrium concentrations of $\text{H}_2$ and $\text{HI}$ were found to be as follows: \([\text{H}_2(g)] = 0.48 \times 10^{-3} \text{ mol/L}\) and \([\text{HI}(g)] = 3.53 \times 10^{-3} \text{ mol/L}\). What is the equilibrium concentration of $\text{I}_2(g)$ under these conditions?

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

3. In the following equilibrium: \( \text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2\text{HI}(g) \) initial amounts of 20.57 moles of hydrogen and 5.22 moles of iodine were allowed to reach equilibrium at 450.0°C in a closed container. At this point the mixture contained 10.22 moles of HI. Calculate $K_c$ at this temperature.
4. In the following equilibrium ethanoic acid (acetic acid), CH₃COOH(0), reacts with ethanol to produce an ester plus water: CH₃COOH(l) + C₂H₅OH(l) ⇌ CH₃CO₂C₂H₅(l) + H₂O(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 (in moles and grams) if K_c = 4.5 at the particular temperature of the reaction?

5. Ethyl ethanoate (CH₃CO₂C₂H₅) can be formed by the reaction of ethene (C₂H₄) with ethanoic acid (CH₃COOH) in an inert solvent according to the equation C₂H₄ + CH₃COOH ⇌ CH₃CO₂C₂H₅. In an experiment 0.50 moles of ethene was allowed to react with 0.20 moles of ethanoic acid at 10.0°C, the total volume being made up to 250. cm³ 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.
6. In the following equilibrium: \(2\text{HI}(g) \rightleftharpoons \text{H}_2(g) + \text{I}_2(g)\) 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 \(\text{I}_2\) was heated in a 2.5 liter vessel and the following reaction occurred: \(\text{I}_2(g) \rightleftharpoons 2 \text{I}(g)\).
   a.) Calculate \([\text{I}_2]\) and \([\text{I}]\) at equilibrium at 600. Kelvin; \(K_c = 2.94 \times 10^{-10}\)

   b.) Calculate \([\text{I}_2]\) and \([\text{I}]\) at equilibrium at 2000. Kelvin; \(K_c = 0.209\)
**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: \( \text{Br}_2(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons 2\text{BrCl}(\text{g}) \) it is found that after starting with 2.0 mols of \( \text{Br}_2(\text{g}) \) and 4.0 mols of \( \text{Cl}_2(\text{g}) \) 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 \( \text{PCl}_5 \) with 0.0450 mol of \( \text{Cl}_2 \) and 0.0450 mol of \( \text{PCl}_3 \) in a 0.5000 liter flask at 250. °C: \( \text{PCl}_5(\text{g}) \rightleftharpoons \text{PCl}_3(\text{g}) + \text{Cl}_2(\text{g}) \); \( K_c = 4.2 \times 10^{-2} \)
   a.) In which direction will the reaction proceed? Show work/explain.

   b.) If \([\text{PCl}_3] = 0.2065 \, M\) at equilibrium, what are the equilibrium concentrations of the other components?
Application Questions

10. The synthesis of ammonia gas, \( \text{NH}_3 \), 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, \( \text{CH}_4 \):

\[
\text{N}_2(g) + 3 \text{H}_2(g) \rightleftharpoons 2 \text{NH}_3(g) \quad \Delta H^\circ_{\text{rxn}} = -91.8 \text{ kJ}
\]

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 \( 1.00 \times 10^{-4} \), and employs and maintains the stoichiometric ratio of 1 mol \( \text{N}_2 \): 3 mol \( \text{H}_2 \). 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 \( \text{H}_2 \) 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 \( \text{N}_2 \): 6 mol \( \text{H}_2 \) 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.*