Kinetics and Equilibrium **Name**_____

Equilibrium Constants

Read from **Lesson 2: Equilibrium** in the **Chemistry Tutorial Section, Chapter 14** of **The Physics Classroom**.
Part b: Equilibrium Constant Expressions **Part c:** Calculations of K and Concentration

Law of Chemical Equilibrium

1. **Law Overview**
   - For a reversible reaction at a given temperature:
     aA + bB ⇄ cC + dD
   - The ratio remains constant at equilibrium. Concentrations are raised to the power of their stoichiometric coefficients.

2. **The Equilibrium Constant, K**
   - K or K_{eq} is known as the **equilibrium constant**
   - The K value is unique to every reaction and dependent only upon the temperature.
   - The K value does not depend on the equilibrium concentrations, but the equilibrium concentrations depend on the K value and the initial concentrations.

$$K_c = \frac{[C]^c \bullet [D]^d}{[A]^a \bullet [B]^b}$$

3. **Writing Equilibrium Expressions (K)**
   - Place product concentrations in the numerator, reactants in the denominator.
   - Use exponents matching coefficients from the balanced equation.
   - Multiply concentrations when there are multiple species.
   - Include only gases and aqueous solutions; exclude solids and liquids.

4. **Types of Equilibrium Constants**
   - Kc uses molar concentrations (mol/L).
   - Kp uses partial pressures for gaseous species:
     aA (g) + bB (g) ⇄ cC (g) + dD(g)

$$K_p = \frac{P_C^c \bullet P_D^d}{P_A^a \bullet P_B^b}$$

5. **Interpreting K Values**
   - K = 1 → Products ≈ Reactants
   - K >> 1 → Products favored
   - K << 1 → Reactants favored

6. **Equilibrium Language**
   - "Equilibrium lies to the right" → favors formation of products
   - "Equilibrium lies to the left" → favors formation of reactants

Example:

$N_2\,(g) + 3\,H_2\,(g) \rightleftarrows 2\,NH_3\,(g)$ At equilibrium: $[N_2] = 2.67$ M, $[H_2] = 3.55$ M, and $[NH_3] = 10.0$ M

$$K_c = \frac{[NH_3]^2}{[N_2] * [H_2]^3} \qquad K_c = \frac{[NH_3]^2}{[N_2] * [H_2]^3} = \frac{(10.0\text{ M})^2}{(2.67\text{ M})*(3.55\text{ M})^3} = 0.837$$

Reactants are favored

K_c for the reverse reaction is $1/K_c$ $= 1/0.837 = 1.19$

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Questions

For each of the following reactions:
a. Write the equilibrium constant expression K_{eq} as either K_c for concentration or K_p for pressure.
b. Calculate the value of K_{eq} as K_c or K_p for the forward reaction, given the equilibrium concentrations or pressures.
c. Based on the given equilibrium concentrations or pressures, determine whether the reaction is product-favored, reactant-favored, or approximately balanced (i.e., [products] ≈ [reactants]).
d. Calculate the value of K_c or K_p for the reverse reaction.

1. $H_2\,(g) + I_2\,(g) \rightleftarrows 2\,HI\,(g)$ At equilibrium: $[H_2] = 0.620$ M, $[I_2] = 0.350$ M, and $[HI] = 1.25$ M.

2. $2\,C_2H_4\,(g) + 2H_2O\,(l) \rightleftarrows 2\,C_2H_6\,(g) + O_2\,(g)$ At equilibrium: $P_{C2H4} = 1.51$ atm, $P_{C2H6} = 1.30$ atm, and $P_{O2} = 0.750$ atm.

3. $Na_2CrO_4(aq) \rightleftarrows 2Na^+\,(aq) + CrO_4^{2-}\,(aq)$ At equilibrium: $[Na_2CrO_4] = 0.0250$ M, $[Na^+] = 1.15$ M, and $[CrO_4^{2-}] = 2.12$ M.

4. $5\,CO(g) + I_2O_5\,(s) \rightleftarrows I_2(g) + 5\,CO_2\,(g)$ At equilibrium: $P_{CO} = 10.5$ atm, $P_{I2} = 13.7$ atm, $P_{CO2} = 5.21$ atm.

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5. $4\ NH_3\ (g) + 3\ O_2\ (g) \rightleftarrows 2\ N_2\ (g) + 6\ H_2O(l)$ At equilibrium: $[NH_3] = 1.25$ M, $[O_2] = 2.89$ M, $[N_2] = 4.88$ M.

6. $N_2O_4\ (g) \rightleftarrows 2\ NO_2(g)$ At equilibrium: $P_{N2O4} = 1.22$ atm, $P_{NO2} = 3.54$ atm.

7 $2\ NOCl\ (g) \rightleftarrows 2\ NO(g) + Cl_2(g)$ At equilibrium: $[NOCl] = 0.500$ M, $[NO] = 0.350$ M, and $[Cl_2] = 0.180$ M.

8. $C\ (s) + H_2O\ (g) \rightleftarrows CO(g) + H_2\ (g)$ At equilibrium: $P_{H2O} = 1.50$ atm, $P_{CO} = 1.22$ atm, $P_{H2} = 1.23$ atm.

9. $NH_3\ (aq) + H_2O(l) \rightleftarrows NH_4^+\ (aq) + OH^-\ (aq)$ At equilibrium: $[NH_3] = 5.65$ M, $[NH_4] = 0.0100$ M, and $[OH^-] = 0.0100$ M.