Totally Epic AP Chem Review: Equilibrium in a Day!

EQUILIBRIUM CONSTANT EXPRESSIONS: The product concentrations appear in the numerator and the reactant concentrations in the denominator. Each concentration is raised to the power of its stoichiometric coefficient in the balanced equation.

- K_c is for concentration (aqueous)
- K_p is for partial pressure (gases)
- "K" values are written without units
- Pure solids and pure liquids do not appear in expression

Practice: Write the expressions for K_c and K_p for the following process:

1. $PCl_5(s) \rightleftharpoons PCl_3(l) + Cl_2(g)$

$K_c = [Cl_2]$, $K_p = P_{Cl_2}$

2. $2\ SO_3(g) \rightleftharpoons 2\ SO_2(g) + O_2(g)$

$K_c = \frac{[SO_2]^2[O_2]}{[SO_3]^2}$, $K_p = \frac{(P_{SO_2})^2(P_{O_2})}{(P_{SO_3})^2}$

Manipulating Reactions

- Stoichiometric Coefficients: If you multiply the coefficients in the equation by a factor, the K is raised to the power of the multiplication factor. 2x is K^2, 3x is K^3, etc
- Reversing Equations: take the reciprocal of K (1/K)
- Adding Equations: multiply respective Ks ($K_1 \times K_2 \times K_3$ ...)

Practice:

1. Calculate the value of K_c for the reaction $2\ NO(g) + Br_2(g) \rightleftharpoons 2\ NOBr(g)$ using the following information.

$2\ NO(g) \rightleftharpoons \cancel{N_2(g)} + \cancel{O_2(g)}$ $\quad K_{c1} = 1 \times 10^{30}$

$\cancel{O_2(g)} + \cancel{N_2(g)} + Br_2(g) \rightleftharpoons 2\ NOBr(g)$ $\quad K_{c2} = 2 \times 10^{-27}$

$2\ NO_{(g)} + Br_{2(g)} \rightleftharpoons 2\ NOBr_{(g)}$

$K_c = K_{c1} \times K_{c2} = (1E30)(2E-27) = \boxed{2000}$

2. For the reaction $2\ X(g) + Y(g) \leftrightarrow 2\ Z(g)$, $K_c = 4.0 \times 10^4$. Determine the value of the equilibrium constant, K_c, for the following reaction:

$2\ Z(g) \leftrightarrow 2\ X(g) + Y(g) \quad K_c = ??$

a. 2.5×10^{-5} b. 2.5×10^{-4} c. 4.0×10^{-5} d. 4.0×10^{-4}

reverse! $K_{new} = \frac{1}{K} = \frac{1}{4E4} = \frac{1}{4}E-4$

$= 0.25E-4 = 2.5E-5$

THE REACTION QUOTIENT, Q: When you need to know the answer to the question, "Is the system at equilibrium?"

A: The answer can be yes or no !

For the general reaction: aA + bB $\leftrightarrows$ cC + dD

$$Q = \frac{[C]^c[D]^d}{[A]^a[B]^b} \text{ or } \frac{(P_C)^c(P_D)^d}{(P_A)^a(P_B)^b}$$

→ Reminder: Q has the appearance of K but the concentrations are not *necessarily* at equilibrium!

What does Q mean?

1. If **K** $>$ **Q**, system not at equilibrium: forward reaction is favored (shift right) to make Q = K.
2. If **K** $=$ **Q**, the system is at equilibrium.
3. If **K** $<$ **Q**, system not at equilibrium: reverse reaction is favored (shift left) to make Q = K.

Practice:

1. The value of the equilibrium constant, K_c, at 25°C is 8.1 for the following reaction: $2\ SO_3(g) \rightleftharpoons 2\ SO_2(g) + O_2(g)$. What must happen for the reaction to reach equilibrium if the initial concentrations of all three species was 2.0 M?

   a. The rate of the forward reaction would increase, and $[SO_3]$ would decrease.
   b. The rate of the reverse reaction would increase, and $[\cancel{SO_3}]$ SO_2 would decrease.
   c. Both the rate of the forward and reverse reactions would increase, and the value for the equilibrium constant would also increase.
   d. No change would occur in either the rate of reaction or the concentrations of any of the species.

$$Q = \frac{[SO_2]^2[O_2]}{[SO_3]^2} = \frac{(2)^2(2)}{(2)^2} = 2$$

K > Q

8.1 > 2

2. Consider the following reaction:

$$CH_4(g) + 2\ H_2S(g) \leftrightarrow CS_2(g) + 4\ H_2(g)$$

1.00 M CH_4, 1.00 M CS_2, 2.00 M H_2S and 2.00 M H_2 are mixed in a reaction vessel at 960°C. At this temperature, the reaction will make more methane and hydrogen sulfide gases. What is a possible K for this reaction?

⇒ shifts left

a. K = 16
b. K = 8
c. K = 4
d. K = 1

K < Q

K < 4

$$Q = \frac{[CS_2][H_2]^4}{[CH_4][H_2S]^2} = \frac{(1)(2)^4}{(1)(2)^2} = 2^2 = 4$$

Calculating with the Equilibrium Expression:

You MUST have a balanced equation.

If the amounts are given in moles BE WARY – you must convert to M (molarity).

1. Write the Equilibrium Constant Expression for K_c or K_p
2. Set up RICE TABLE
   R = Balanced Reaction
   I = Initial concentrations
   C = Change in concentration Remember: Everything changes stoichiometrically!
   E = Equilibrium concentrations These are the concentrations (pressures) of all species at equilibrium

Hint: If none of the initial concentrations are zero, then Q must be calculated first to determine the direction of the shift (who gains and loses) before calculating the equilibrium concentrations.

Practice:

1. Ammonia and oxygen react according to the following equilibrium: $4\ NH_3(g) + 3\ O_2(g) \rightleftharpoons 2\ N_2(g) + 6\ H_2O(g)$.
   A 1.0 liter flask is initially filled with 4.0 mol of oxygen and 3.0 mol of ammonia, and 1.0 mol of N_2 is present at equilibrium. How much oxygen is present at equilibrium?

   a. 1.0 mol O_2 b. 1.5 mol O_2 c. 2.5 mol O_2 d. 3.0 mol O_2

$4NH_3$	$+ 3O_2$	$\rightleftharpoons 2N_2$	$+ 6H_2O$
3	4	ϕ	ϕ
$-4x$	$-3x$	$+2x$	$+6x$
		1.0	

$\Rightarrow x = 0.5 \Rightarrow [O_2] = 4 - 3x = 4 - 3(0.5) = 4 - 1.5 = 2.5$

2. Here is a general reaction with a K value of 16: $A(aq) + B(aq) \rightleftharpoons 2\ C(aq)$.
   Initially, $[A] = [B] = 2.0$ M. Solve for the equilibrium concentration of each substance.

   a. $[A] = [B] = 0.67$ M, $[C] = 1.3$ M
   b. $[A] = [B] = 1.6$ M, $[C] = 0.88$ M
   c. $[A] = [B] = 0.67$ M, $[C] = 2.7$ M
   d. $[A] = [B] = 0.50$ M, $[C] = 3.0$ M

A	+ B	$\rightleftharpoons$ 2C
2	2	ϕ
$-x$	$-x$	$+2x$
$2-x$	$2-x$	$2x$

$$K_c = \frac{[C]^2}{[A][B]} = \frac{(2x)^2}{(2-x)^2} = 16$$

$$\Rightarrow \frac{2x}{2-x} = 4 \quad 2x = 4(2-x) = 8 - 4x$$

$$6x = 8 \Rightarrow x = \frac{8}{6} = 1.33$$

$[A] = [B] = 2 - 1.33 = 0.67$

$[C] = 2(1.33) = 2.66$

3. The reaction below came to equilibrium at a temperature of 100°C. At equilibrium the partial pressure due to NOBr was 4 atm, the partial pressure due to NO was 4 atm, and the partial pressure due to Br_2 was 2 atm. What is the equilibrium constant, K_p, for this reaction at 100°C?

$$2\ NOBr(g) \rightleftharpoons 2\ NO(g) + Br_2(g)$$

   a. ¼ b. ½ c. 1 d. 2

$$K_p = \frac{(P_{NO})^2 (P_{Br_2})}{(P_{NOBr})^2} = \frac{(4)^2(2)}{(4)^2} = 2$$