Manipulating Equilibrium Constant Expressions

Remember, for the reaction: $\mathbf{a\ A_{(aq)} + b\ B_{(aq)} <=> c\ C_{(aq)} + d\ D_{(aq)}}$,

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

- Products in numerator, reactants in denominator
- Raise the stoichiometric value to the same factor for each species present
- Only gases and dissolved species appear in equilibrium constant expressions
- Solids and liquids do not appear in equilibrium constant expressions
- Remember to watch for units!

1. *Do not include solids and liquids in equilibrium calculations, only gases and dissolved species*

Example 1: $\mathbf{C_{(s)} + {}^1/_2\ O_{2(aq)} <=> CO_{(aq)}}$

$$K_1 = \frac{[CO]}{[O_2]^{1/2}} = 4.6*10^{23}\ M^{1/2} \text{ at } 25\ ^\circ C$$

2. *If doubling reaction, square K; if tripling, cube K; etc.*

Example 2: $\mathbf{2\ C_{(s)} + O_{2(aq)} <=> 2\ CO_{(aq)}}$

$$K_2 = \frac{[CO]^2}{[O_2]} = (K_1)^2 = (4.6*10^{23})^2 = 2.1*10^{47}\ M \text{ at } 25\ ^\circ C$$

Also, if reaction*3, $K = (K_1)^3$; if reaction halved, $K = (K_1)^{1/2}$; *etc.*

3. *If reactants and products are "flipped", take 1/K for new value..*

Example 3: $\mathbf{CO_{(aq)} <=> C_{(s)} + {}^1/_2\ O_{2(aq)}}$

$$K_3 = \frac{[O_2]^{1/2}}{[CO]} = \frac{1}{K_1} = \frac{1}{4.6*10^{23}} = 2.2*10^{-24}\ M^{-1/2} \text{ at } 25\ ^\circ C$$

4. *Temperature changes will affect the value of K by either adding or subtracting from the original value.*

Example 4: $C_{(s)} + {}^{1}/_{2}\, O_{2(aq)} \iff CO_{(aq)}$

$$K_4 = \frac{[CO]}{[O_2]^{1/2}} = \mathbf{9.7*10^{23}\ M^{1/2}\ at\ 37\ ^\circ C}$$

5. *Reactions in the gas phase use K_p expressions which are similar to K_c expressions*

Example 5: $C_{(s)} + {}^{1}/_{2}\, O_{2(g)} \iff CO_{(g)}$

$$K_5 = \frac{P_{CO}}{P_{O_2}^{1/2}} = K_p, \quad \textit{and if at 25 °C (298 K),}$$

$$K_p = K_c(RT)^{\Delta n} = 4.6*10^{23}(0.082057*298)^{1-1/2} = \mathbf{2.3*10^{24}\ atm^{1/2}}$$

R = gas constant, T = Kelvin temperature, P in atm

6. *If adding reactions, multiply the respective K values together*

Example 6:

$C_{(s)} + {}^{1}/_{2}\, O_{2(aq)} \iff \cancel{CO_{(aq)}}$ $K_1 = 4.6*10^{23}\ M^{1/2}$

$\cancel{CO_{(aq)}} + {}^{1}/_{2}\, O_{2(aq)} \iff CO_{2(aq)}$ $K_6 = 1.7*10^{15}\ M^{-1/2}$

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net reaction: $C_{(s)} + O_{2(aq)} \iff CO_{2(aq)}$ K_7

Assume at 25 °C:

$$K_7 = K_1 * K_6 = \frac{[CO]}{[O_2]^{1/2}} * \frac{[CO_2]}{[CO][O_2]^{1/2}} = (4.6*10^{23})(1.7*10^{15}) = \mathbf{7.8*10^{38}}\ \textit{unitless}$$