Mass Action Expressions and Rice Tables - Supplemental Worksheet KEY

Mass Action Expressions:
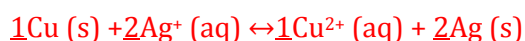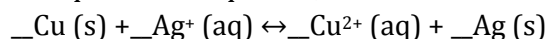
1. Given the following chemical equilibrium equation, write the K expression.

$$CaCO_3 (s) \leftrightarrow CaO (s) + CO_2 (g)$$

There are two possible choices for the K expression. K_c or K_p.

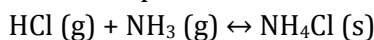$$K_c = [CO_2] \qquad and \qquad K_p = P_{CO2}$$

2. Given the following chemical equilibrium equation, first balance then write the K expression.

$$\_Cu (s) + \_Ag^+ (aq) \leftrightarrow \_Cu^{2+} (aq) + \_Ag (s)$$

$$\underline{1}Cu (s) + \underline{2}Ag^+ (aq) \leftrightarrow \underline{1}Cu^{2+} (aq) + \underline{2}Ag (s)$$

$$K_c = \frac{[Cu^{2+}]}{[Ag^+]^2}$$

3. Given the following chemical equilibrium equation, write the K expression.

$$HCl (g) + NH_3 (g) \leftrightarrow NH_4Cl (s)$$

There are two possible choices for the K expression. K_c or K_p.

$$K_c = \frac{1}{[HCl][NH_3]} \qquad and \qquad K_p = \frac{1}{P_{HCl}P_{NH_3}}$$

4. Given the following chemical equilibrium equation, write the K expression.

$$6CO_2 (g) + 6H_2O (l) \leftrightarrow C_6H_{12}O_6 (s) + 6O_2 (g)$$
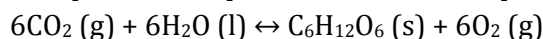
There are two possible choices for the K expression. K_c or K_p.

$$K_c = \frac{[O_2]^6}{[CO_2]^6} \qquad and \qquad K_p = \frac{P_{O_2}{}^6}{P_{CO_2}{}^6}$$

5. Gaseous phosphorus consists of P_4 molecules at moderate temperatures. At these moderately elevated temperatures, phosphoryl chloride ($POCl_3$) can be produced in the vapor phase from <u>the gaseous elements</u>. Write a balanced chemical equation and an equilibrium expression for this system.
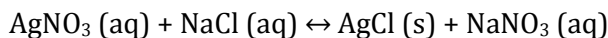
$$P_4(g) + 6Cl_2(g) + 2O_2(g) \leftrightarrow 4POCl_3(g)$$

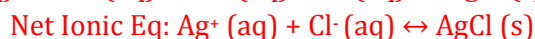$$K_p = \frac{(P_{POCl_3})^4}{(P_{P_4})(P_{Cl_2})^6(P_{O_2})^2}$$

Rice Tables:

1. Given the following formula unit equilibrium equation and initial substance concentrations. First, write out the net ionic equation for this reaction and then write the K expression in terms of the change in the concentration of the silver ion defined by the generic variable "x".

$$AgNO_3 \text{ (aq)} + NaCl \text{ (aq)} \leftrightarrow AgCl \text{ (s)} + NaNO_3 \text{ (aq)}$$
$$C_{AgNO3} = 0.1M \text{ and } C_{NaCl} = 0.3M \text{ and } C_{NaNO3} = 0M$$

Total Ionic Eq: Ag^+ (aq) + NO_3^- (aq) + Na^+ (aq) + Cl^- (aq) ↔ AgCl (s) + Na^+ (aq) + NO_3^- (aq)
Net Ionic Eq: Ag^+ (aq) + Cl^- (aq) ↔ AgCl (s)

The initial concentrations were given for the soluble compounds. However, a 0.1M solution of $AgNO_3$ results in 0.1M concentration of the Ag^+ because Ag^+ is in a 1:1 ratio with its soluble salt. The same reasoning could be applied to find the concentration of Cl^- to be 0.3M.

R	Ag^+ (aq)	+	Cl^- (aq) ↔	AgCl (s)
I	0.1M		0.3M	---
C	-x		-x	---
E	0.1M -x		0.3M-x	---

$$K_c = \frac{1}{[Ag^+][Cl^-]}$$

$$K_c = \frac{1}{[0.1-x][0.3-x]}$$

Here we define 1x to mean the small change in Ag^+, however, since Cl^- has the same molar coefficient as Ag^+, they both experience a change of - 1x.

2. Given the following chemical equilibrium equation and initial substance concentrations, write the K expression in terms of the change in concentration of H_3O^+ defined as "x".
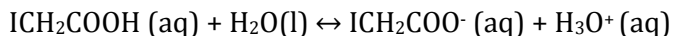
$$ICH_2COOH \text{ (aq)} + H_2O(l) \leftrightarrow ICH_2COO^- \text{ (aq)} + H_3O^+ \text{ (aq)}$$
$$C_{ICH2COOH} = 2.0 \text{ M}$$

R	ICH_2COOH (aq) +	$H_2O(l)$ ↔	ICH_2COO^- (aq) +	H_3O^+ (aq)
I	2.0 M	---	0	0
C	-x	---	+x	+x
E	2.0-x	---	x	x

$$K_c = \frac{[H_3O^+][ICH_2COO^-]}{[ICH_2COOH]}$$

$$K_c = \frac{[x][x]}{[2.0-x]}$$

Here we chose to define 1x to mean the small change in concentration of H_3O^+, however, since all of the products and reactants have the same molar coefficient as H_3O^+, they all experience a change of either + or - 1x as well!

3. Given the following chemical equilibrium equation and initial substance concentrations, write the K expression in terms of "x".

$$4Fe\ (s) + 3O_2\ (g) \leftrightarrow 2Fe_2O_3\ (s)$$
$$P_{O2} = 1.0\ atm$$
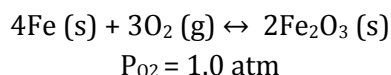
R	4Fe (s)	+	$3O_2$ (g) $\leftrightarrow$	$2Fe_2O_3$ (s)
I	---		1.0atm	---
C	---		-x	---
E	---		1.0 - x	---

$$K_p = \frac{1}{P_{O_2}{}^3}$$

$$K_p = \frac{1}{(1.0-x)^3}$$

Here we chose to define -1x to mean the small change in the overall concentration of O_2, the reason we chose to use -1x and NOT -3x is that we didn't have to worry about the concentration changes of anything else in the reaction! However, we could have easily used 3x and come up with the same valid answers when we chose to solve for the equilibrium concentration of O_2. As the scientist, YOU get to define what x means for your problem. By convention, we often place to molar coefficient of the substance in front of its "x" change, which is a useful method when looking at reactions with multiple substances changing that have different molar coefficients (see problem #5 below).

4. Given the following chemical equilibrium equation and initial substance concentrations, write the K expression in terms of the change in concentration of the number of moles of reaction "x"

$$3C_2H_2\ (g) + 3H_2\ (g) \leftrightarrow C_6H_{12}\ (l)$$
$$P_{C2H2} = 0.2\ atm\ and\ P_{H2} = 0.2\ atm$$
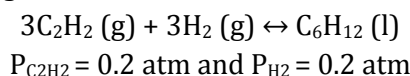
| R	$3C_2H_2$ (g)	+	$3H_2$ (g) $\leftrightarrow$	C_6H_{12} (l)
I	0.2atm		0.2atm	---
C	-3x		-3x	---
E	0.2 - 3x		0.2 - 3x	---

$$K_p = \frac{1}{(P_{C_2H_2})^3(P_{H_2})^3}$$

$$K_p = \frac{1}{(0.2-3x)^3(02.-3x)^3} = \frac{1}{(0.2-3x)^6}$$

Here, *by convention*, we chose to use -3x to represent the change in partial pressures for both of the reactants. We could have just as easily used -1x for both of these changes - as long as the change in concentrations for the reactants follow the mole ratios of the substances the math will work out. In

this case the change in both reactants will be equal in magnitude because they have the same molar coefficient. We could have used -10y or -4.5x or something else if we really wanted, but we generally select simpler numbers when possible.

5. Given the following chemical equilibrium equation and initial substance concentrations, let's say the K value is 1.3×10^{-1}. First decide whether or not the reaction will drive forward to the products or backwards to the reactants by calculating Q with the given initial conditions. If the reaction does drive forward, write K expression in terms of the change in concentration of the number of moles of reactant A using the generic variable "x".

$$A \text{ (aq)} + 2B \text{ (aq)} \leftrightarrow 2C \text{ (aq)}$$
$$C_A = 2.0 \text{ M}, C_B = 0.3M \text{ and } C_C = 0.1M$$
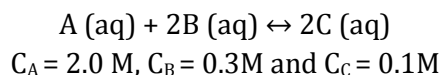
$$Q = \frac{[C]^2}{[A][B]^2} = \frac{[0.1]^2}{[2.0][0.3]^2} = 0.056$$

$$0.056 < 0.13$$

$$Q < K$$

Because Q is less than K, the reaction has not yet reached equilibrium and the reaction will drive toward the products. We can set up a RICE table to show this progression:

R	A (aq)	+	2B (aq)	↔	2C (aq)
I	2.0M		0.3M		0.1M
C	-x		-2x		+2x
E	2.0 - x		0.3 - 2x		0.1 + 2x

$$K_c = \frac{[C]^2}{[A][B]^2}$$

$$K_c = \frac{[0.1 + 2x]^2}{[2.0 - x][0.3 - 2x]^2}$$

Here we define -1x to mean the small change in reactant A, however, since B and C do not have the same molar coefficient as A, they each experience a change twice that of A, so -2x for B and +2x for C.

What if we had wanted to use -1x as the change in reactant B?? That would be acceptable, although a more unpopular choice just because of the math. Looking at our molar coefficient ratios in the chemical equation, we know that any change in reactant B is going to relate to twice that of a change in reactant A, but the same magnitude of change for product C. So our RICE table would look like this:

R	A (aq)	+	2B (aq)	↔	2C (aq)
I	2.0M		0.3M		0.1M
C	-0.5x		-x		+x
E	2.0 - 0.5x		0.3 - x		0.1 + x

$$K_c = \frac{[C]^2}{[A][B]^2}$$

$$K_c = \frac{[0.1+x]^2}{[2.0-0.5x][0.3-x]^2}$$

As long as we follow through correctly with our definition of x, any solving of the RICE tables and K should give the same answer as the previous definition of x. Try it out and see!