Name: ANSWER KEY

Chemistry 30

Unit 3: Chemical Equilibrium

Assignment 2: 2-1 to 2-2

1. a) What is meant by a reversible reaction?

   a reaction that can go in both forward and reverse directions.

   b) Are all chemical reactions reversible? ***No***

   c) Are all reversible reactions always at equilibrium? ***No***

   d) Does a reaction have to be reversible in order to reach equilibrium? ***Yes***

   e) What, exactly, is equal at equilibrium? (define equilibrium)

   When the rate of the forward reaction equals the rate of the reverse direction.

   f) How is equilibrium different from a steady state system?

   A steady state occurs in an open system, where there is continual addition of reactants and removal of products. An example would be an assembly line. An equilibrium occurs in a closed system, with no additional reactants being added or products being removed.

2. Write the equilibrium expression for each of the following reactions. Be sure to pay attention to physical states:

   a) $Br_2\,(g) + 5\,F_2\,(g) \rightleftharpoons 2\,BrF_5(g)$

   $$K_{eq} = \frac{[BrF_5]^2}{[Br_2][F_2]^5}$$

   b) $4\,HCl\,(g) + O_2(g) \rightleftharpoons 2\,H_2O\,(g) + 2\,Cl_2\,(g)$

   $$K_{eq} = \frac{[H_2O]^2[Cl_2]^2}{[HCl]^4[O_2]}$$

   c) $5\,Fe^{+2}(aq) + MnO_4^-(aq) + 8\,H^+(aq) \rightleftharpoons 5\,Fe^{+3}(aq) + Mn^{+2}(aq) + 4\,H_2O(l)$

   $$K_{eq} = \frac{[Fe^{3+}]^5[Mn^{2+}]}{[Fe^{2+}]^5[MnO_4^-][H^+]^8}$$

3. For each of the following reactions, state whether the value of the equilibrium constant favours the formation of reactants, products, or both sides equally.

   a) $I_2(g) + Cl_2(g) \rightleftharpoons 2\ ICl(g)$ $K_{eq} = 2 \times 10^6$ ***products***

   b) $H_2(g) + Cl_2(g) \rightleftharpoons 2\ HCl(g)$ $K_{eq} = 1.08$ ***equal***

   c) $I_2(g) \rightleftharpoons I(g) + I(g)$ $K_{eq} = 3.8 \times 10^{-7}$ ***reactants***

4. Molecular chlorine decomposes into atoms according to the reaction:

   $Cl_2\ (g) \rightleftharpoons 2\ Cl\ (g)$

   The equilibrium constant for the reaction at 25°C is 1.4×10^{-38}. Would many chlorine atoms be present at this temperature? How do you know?

   The reactants are clearly favored since K_{eq} is much less than 1. The reactant side of the equation shows *molecular* chlorine. Molecular chlorine is thus far more abundant than individual chlorine atoms.

5. Calculate K_{eq} for each of the following. Be sure to set up the equilibrium constant expression first, before substituting in the values.

   Show your work! Pay attention to exponents!

   a) $H_2(g) + Cl_2(g) \rightleftharpoons 2\ HCl$

   $[H_2] = 1.0 \times 10^{-2}$ M

   $[Cl_2] = 1.0 \times 10^{-2}$ M

   $[HCl] = 1.0 \times 10^{-2}$ M

$$K_{eq} = \frac{[HCl]^2}{[H_2][Cl_2]} = \frac{(1.0 \times 10^{-2})^2}{(1.0 \times 10^{-2})(1.0 \times 10^{-2})} = \frac{1.0 \times 10^{-4}}{1.0 \times 10^{-4}} = 1$$

b) $N_2(g) + 3\ H_2(g) \rightleftarrows 2\ NH_3(g)$

$[N_2] = 4.4 \times 10^{-2}$ M
$[H_2] = 1.2 \times 10^{-1}$ M
$[NH_3] = 3.4 \times 10^{-3}$ M

$$K_{eq} = \frac{[NH_3]^2}{[N_2][H_2]^3} = \frac{(3.4\times10^{-3})^2}{(4.4\times10^{-2})(1.2\times10^{-1})} = \frac{1.156\times10^{-5}}{7.6\times10^{-5}} = 0.152$$

c) $2\ CO(g) + O_2\ (g) \rightleftarrows 2\ CO_2\ (g)$

$[CO] = 2.5 \times 10^{-3}$ M
$[O_2] = 1.6 \times 10^{-3}$ M
$[CO_2] = 3.2 \times 10^{-2}$ M

$$K_{eq} = \frac{[CO_2]^2}{[CO]^2[O_2]} = \frac{(3.2\times10^{-2})^2}{(2.5\times10^{-3})^2(1.6\times10^{-3})} = \frac{1.024\times10^{-3}}{1.0\times10^{-8}} = 1.02\times10^5$$

d) $CH_4(g) + H_2O(g) \leftrightarrow CO(g) + 3\ H_2(g)$

$[CH_4] = 2.97 \times 10^{-3}$ M
$[H_2O] = 7.94 \times 10^{-3}$ M
$[CO] = 5.45 \times 10^{-3}$ M
$[H_2] = 2.1 \times 10^{-3}$ M

$$K_{eq} = \frac{[CO][H_2]^3}{[CH_4][H_2O]} = \frac{(5.45\times10^{-3})(2.1\times10^{-3})^2}{(2.97\times10^{-3})(7.94\times10^{-3})} = \frac{5.05\times10^{-11}}{2.36\times10^{-5}} = 2.14\times10^{-6}$$

6. For the following reaction at equilibrium at 2000°C, the concentration of N_2 and O_2 are both 5.2 M.

$$N_2(g) + O_2(g) \rightleftharpoons 2\ NO(g) \qquad K_{eq} = 6.2 \times 10^{-4}$$

Calculate the concentration of NO at equilibrium. Show your work; pay careful attention to exponents.

$$K_{eq} = \frac{[NO]^2}{[N_2][O_2]}$$

Let *x* represent the value of the unknown concentration, [NO]

Substitute the known and unknown values into the equation & solve

$$6.2 \times 10^{-4} = \frac{x^2}{[5.2][5.2]}$$

Rearrange to isolate x^2:

$$(6.2 \times 10^{-4})(5.2)(5.2) = x^2$$

$$x^2 = 0.01676$$

$$\sqrt{x^2} = \sqrt{0.01676}$$

$$x = 0.13M = [NO]$$

7. Acetic acid, $HC_2H_3O_2$, is in equilibrium with its ions:

$$HC_2H_3O_2(aq) \rightleftharpoons H^+(aq) + C_2H_3O_2^-(aq) \qquad K_{eq} = 1.8 \times 10^{-5}$$

At equilibrium, the concentration of the ions are: $[H^+] = 1.33 \times 10^{-3}$ M

$[C_2H_3O_2^-] = 1.33 \times 10^{-3}$ M

Calculate the concentration of the acid, $HC_2H_3O_2$.

$$K_{eq} = \frac{[H^+][C_2H_3O_2^-]}{[HC_2H_3O_2]}$$

Let x = the unknown, [$HC_2H_3O_2$]

$$1.8 \times 10^{-5} = \frac{(1.33 \times 10^{-3})(1.33 \times 10^{-3})}{[x]}$$

$$(1.8 \times 10^{-5})(x) = 1.77 \times 10^{-6}$$

Rearrange to isolate x:

$$x = \frac{1.77 \times 10^{-6}}{1.8 \times 10^{-5}} = 9.8 \times 10^{-2}\,M = [HC_2H_3O_2]$$