$H_2$ 2.016 g/mol
CO 28.01
$CH_4$ 16.04
$H_2O$ 18.016

Chem 1B Test 1
June 22, 2006

Key

Show work for credit.

1. A mixture of $CH_4$ and $H_2O$ is passed over a nickel catalyst at 1000K. The emerging gas is collected in a 5.00 L flask and is found to contain 8.62 g of CO, 2.60 g of $H_2$. 43.0 g of $CH_4$, and 48.4 g of $H_2O$.

   $[H_2] = \frac{2.6 g / 2.016 g}{5.00 L} = 0.258 M$

   a. Write a balanced equation for this reaction.

   $CH_4 + H_2O \rightleftharpoons CO + 3 H_2$

   $[CO] = 0.06155 M$

   b. Assuming equilibrium has been reached calculate $K_c$ and $K_p$ at 1000°K.

   $[CH_4] = 0.5362 M$

   $[H_2O] = 0.5373 M$

   $$K_c = \frac{[H_2]^3[CO]}{[CH_4][H_2O]} = \frac{0.258^3 \times 0.06155}{0.5362 \times 0.5373} = 3.67 \times 10^{-3}$$

   $$K_p = K_c(RT)^{\Delta n} = 3.6 \times 10^{-3}(0.08206 \times 1000)^2 = 24.2$$

   (Most hydrogen is currently produced this way from natural gas! The CO is then oxidized and discarded as $CO_2$. So producing hydrogen this way does not solve the global warming problem!)

2. Using data from attached Table 9.2, calculate the equilibrium constant $K_c$ at 25 °C for the following reaction: $CH_3COOH + CO_3^{-2} \leftrightarrow HCO_3^- + CH_3COO^-$

   | acid | $K_a$ |
   |---|---|
   | $CH_3COOH$ | $1.8 \times 10^{-5}$ |
   | $HCO_3^-$ | $5.6 \times 10^{-11}$ |

   add
   $CH_3COOH \rightleftharpoons CH_3COO^- + H^+$   K = $1.8 \times 10^{-5}$
   $H^+ + CO_3^{2-} \rightleftharpoons HCO_3^-$   $\frac{1}{5.6 \times 10^{-11}}$

   $$K_c = \frac{1.8 \times 10^{-5}}{5.6 \times 10^{-11}} = 3.2 \times 10^5$$

3. Calculate $[H^+]$, pH, $[OH^-]$, and pOH for the following solutions:

| | $[H^+]$ | pH | $[OH^-]$ | pOH |
|---|---|---|---|---|
| a. 0.030 M solution of $HNO_3$ (nitric acid) | 0.030 M | 1.52 | $3.3 \times 10^{-13}$ M | 12.47 |
| b. 0.030 M solution of $NH_4Cl$ (ammonium chloride) | $3.3 \times 10^{-6}$ M | 5.49 | $3.1 \times 10^{-9}$ M | 8.51 |

$NH_4^+ \rightarrow H^+ + NH_3$   $K_a = 5.56 \times 10^{-10}$

| | $[NH_4^+]$ | $[NH_3]$ | $H^+$ |
|---|---|---|---|
| i | 0.030 | 0 | 0 |
| c | −x | x | x |
| e | 0.030 − x | x | x |

$$\frac{x^2}{0.030 - x} = 5.56 \times 10^{-10}$$

$$x \sim \sqrt{0.030 \times 5.56 \times 10^{-10}} = 3.26 \times 10^{-6}$$

4. Calculate $[H^+]$, pH, $[OH^-]$, and pOH for the following solutions:

$K_a = 1.8 \times 10^{-4}$

| | $[H^+]$ | pH | $[OH^-]$ | pOH |
|---|---|---|---|---|
| a. 0.030 M solution of HCOOH (formic acid) | 0.0022 M | 2.65 | $4.45 \times 10^{-12}$ | 11.35 |
| b. 0.030 M solution of HCOONa (sodium formate) | $7.7 \times 10^{-9}$ | 8.11 | $1.3 \times 10^{-6}$ | 5.89 |

$$\frac{x^2}{0.030 - x} = 1.8 \times 10^{-4} \quad x_1 = 0.0023 \quad x_2 = 0.0022$$

$K_b = 5.55 \times 10^{-11}$

$HCOO^- + H_2O \rightleftarrows HCOOH + OH^-$

| | $[HCOO^-]$ | $[HCOOH]$ | $[OH^-]$ |
|---|---|---|---|
| i | 0.030 | 0 | 0 |
| c | $-x$ | $x$ | $x$ |
| e | $0.030 - x$ | $x$ | $x$ |

$$\frac{x^2}{0.030 - x} = 5.55 \times 10^{-11} \quad x = 1.3 \times 10^{-6}$$

5. From problems 3 & 4
   a. which acid is a strong acid? and what is its conjugate base?

      $HNO_3$ $NO_3^-$

   b. which acids are weak acids? and what are their conjugate bases?

      $NH_4^+$ $NH_3$

      $HCOOH$ $HCOO^-$

   c. which is the weakest acid?

      $NH_4^+$

   d. of the three acids, which acid has the weakest conjugate base?

      $HNO_3$

6. Hydrogen, a potential fuel, is found in great abundance in water. However, before hydrogen can be used as fuel, the water must be split into $H_2$ and $O_2$. One possibility is thermal decomposition, but this requires very high temperatures. However, even at 1000°C, $K_c = 7.3 \times 10^{-18}$ for the reaction:

$$2H_2O(g) \leftrightarrow 2H_2(g) + O_2(g)$$

$x \sim 2.6 \times 10^{-7}$ M

$[H_2] = 2x = 5.2 \times 10^{-7}$ M

Suppose at 1000°C the $H_2O$ concentration in a reaction vessel is set initially at 0.100 M, what will the $H_2$ concentration be when the reaction reaches equilibrium? (Hint: set up an "i-c-e" concentration table.)

| | $[H_2O]$ | $[H_2]$ | $[O_2]$ |
|---|---|---|---|
| i | 0.100 | 0 | 0 |
| c | $-2x$ | $2x$ | $x$ |
| e | $0.100 - 2x$ | $2x$ | $x$ |

$$\frac{[H_2]^2[O_2]}{[H_2O]^2} = \frac{(2x)^2 x}{(0.100 - 2x)^2} = 7.3 \times 10^{-18}$$

$$\frac{4x^3}{0.01} \sim 7.3 \times 10^{-18}$$

$$x \sim \sqrt[3]{\frac{7.3 \times 10^{-20}}{4}} = 2.6 \times 10^{-7}$$

assume 1000 mL each

$$\frac{1000.\ g}{18.016\ g/mol} = 55.51\ mol\ H_2O$$

7. Extra: The cooling system of a car is filled with a solution formed by mixing equal volumes of water (density = 1.00 g/mL) and ethylene glycol, $C_2H_6O_2$ (density = 1.12 g/mL).

62.07

a. What are the mole fractions of water and ethylene glycol?

$$\frac{1120\ g}{62.07\ g/mol} = 18.04\ mol\ C_2H_6O_2$$

$$\chi_{H_2O} = \frac{n_{H_2O}}{n_{H_2O} + n_{C_2H_6O_2}} = \frac{55.51}{55.51 + 18.04} = 0.755$$

$$\chi_{C_2H_6O} = 1.000 - 0.755 = 0.245$$

b. What is the molality of ethylene glycol?

$$\text{molality} = \frac{n_{C_2H_6O_2}}{\text{mass } H_2O\ (kg)} = \frac{18.04\ mol}{1.000\ kg} = 18.04\ molal$$

c. What is the vapor pressure of the solution at 100°C?

$$P_{H_2O} = \chi_{H_2O}\, P^{o}_{H_2O} = 0.755 \times 1.00\ atm = 0.755\ atm$$

d. What are the freezing and boiling points of the solution? (for $H_2O$ $K_f$ = 1.86°C/molal and $K_b$= 0.51°C/molal.)

$$\Delta T_b = 0.51\,°C/m \times 18.04\ m = 9.2\,°C$$

$$T_b = T_{b,\ pure\ H_2O} + \Delta T_b = 109.2\,°C$$

$$\Delta T_f = -1.86\,°C/m \times 18.04\ m = -33.6\,°C$$

$$T_f = 0\,°C - 33.6\,°C = -33.6\,°C$$