

# Key

H <sub>2</sub>	2.016	g/mol
CO	28.01	
CH <sub>4</sub>	16.04	
H <sub>2</sub> O	18.016	

Show work for credit.

1. A mixture of CH<sub>4</sub> and H<sub>2</sub>O 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<sub>2</sub>, 43.0 g of CH<sub>4</sub>, and 48.4 g of H<sub>2</sub>O.

- a. Write a balanced equation for this reaction.



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

$$K_c = \frac{[\text{H}_2]^3 [\text{CO}]}{[\text{CH}_4] [\text{H}_2\text{O}]}$$

$$K_c = \frac{0.258^3 \times 0.06155}{0.5362 \times 0.5373} = 3.67 \times 10^{-3}$$

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

$$[\text{H}_2] = \frac{2.60 \text{ g} / 2.016 \text{ g/mol}}{5.00 \text{ L}} = 0.258 \text{ M}$$

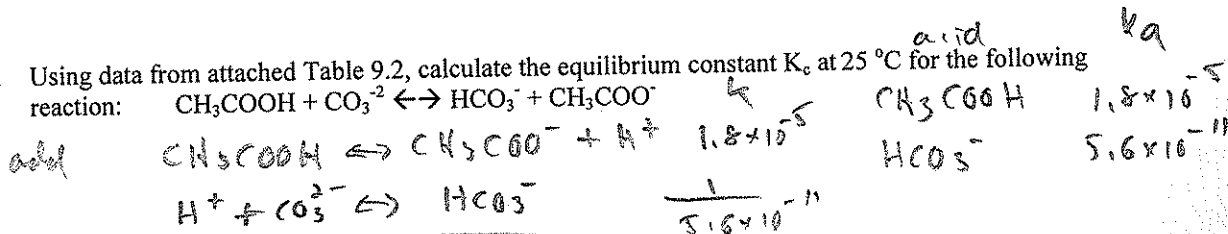
$$[\text{CO}] = 0.06155 \text{ M}$$

$$[\text{CH}_4] = 0.5362 \text{ M}$$

$$[\text{H}_2\text{O}] = 0.5373 \text{ M}$$

(Most hydrogen is currently produced this way from natural gas! The CO is then oxidized and discarded as CO<sub>2</sub>. 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:



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

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

	$[\text{H}^+]$	pH	$[\text{OH}^-]$	pOH
a. 0.030 M solution of HNO <sub>3</sub> (nitric acid)	0.030 M	1.52	$3.3 \times 10^{-13}$ M	12.47
b. 0.030 M solution of NH <sub>4</sub> Cl (ammonium chloride)	$3.3 \times 10^{-6}$ M	5.49	$3.1 \times 10^{-9}$ M	8.51



i	$[\text{NH}_4^+]$	$[\text{NH}_3]$	$[\text{H}^+]$
i	0.030	0	0
c	-x	x	x
o	0.030 - x	x	x

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

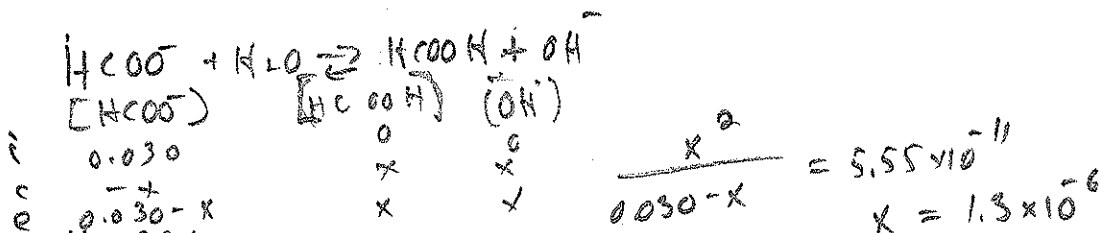
$$x \approx \sqrt{0.030 \times 5.56 \times 10^{-10}} = 3.26 \times 10^{-6}$$

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    0.0022 M    2.65     $4.45 \times 10^{-12}$     11.35  
 (formic acid)

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

$K_b = 5.55 \times 10^{-11}$   
 b. 0.030 M solution of HCOONa     $7.7 \times 10^{-9}$     8.11     $1.3 \times 10^{-6}$     5.89  
 (sodium formate)



5. From problems 3 & 4

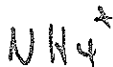
a. which acid is a strong acid? and what is its conjugate base?



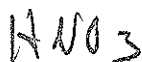
b. which acids are weak acids? and what are their conjugate bases?



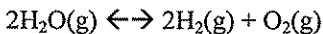
c. which is the weakest acid?



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

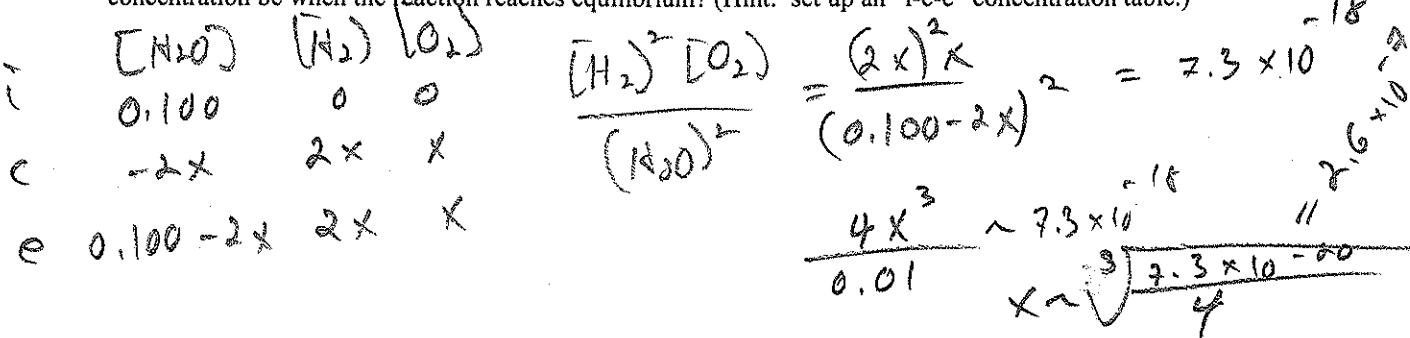


6. Hydrogen, a potential fuel, is found in great abundance in water. However, before hydrogen can be used as fuel, the water must be split into  $H_2$  and  $O_2$ . One possibility is thermal decomposition, but this requires very high temperatures. However, even at  $1000^\circ C$ ,  $K_c = 7.3 \times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



$x \sim 2.6 \times 10^{-7} M$   
 $[H_2] = 2x = 5.2 \times 10^{-7} M$

Suppose at  $1000^\circ C$  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.)



assume 1000 mL each

$$\frac{1000. \text{ g}}{18.016 \text{ g/mol}} = 55.51 \text{ mol H}_2\text{O}$$

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,  $\text{C}_2\text{H}_6\text{O}_2$  (density = 1.12 g/mL).

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

$$\chi_{\text{H}_2\text{O}} = \frac{n_{\text{H}_2\text{O}}}{n_{\text{H}_2\text{O}} + n_{\text{C}_2\text{H}_6\text{O}_2}} = \frac{55.51}{55.51 + 18.04} = 0.755$$

$$\frac{1120 \text{ g}}{62.07 \text{ g/mol}} = 18.04 \text{ mol C}_2\text{H}_6\text{O}_2$$

$$\chi_{\text{C}_2\text{H}_6\text{O}_2} = 1.000 - 0.755 = 0.245$$

b. What is the molality of ethylene glycol?

$$\text{molality} = \frac{n_{\text{C}_2\text{H}_6\text{O}_2}}{\text{mass H}_2\text{O (kg)}} = \frac{18.04 \text{ mol}}{1.000 \text{ kg}} = 18.04 \text{ molal}$$

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

$$P_{\text{H}_2\text{O}} = \chi_{\text{H}_2\text{O}} P_{\text{H}_2\text{O}}^{\circ} = 0.755 \times 1.00 \text{ atm} = 0.755 \text{ atm}$$

d. What are the freezing and boiling points of the solution? (for  $\text{H}_2\text{O}$   $K_f = 1.86^\circ\text{C/molal}$  and  $K_b = 0.51^\circ\text{C/molal}$ .)

$$\Delta T_b = 0.51^\circ\text{C/m} \times 18.04 \text{ m} = 9.2^\circ\text{C}$$

$$T_b = T_b^{\text{pure H}_2\text{O}} + \Delta T_b = 100^\circ\text{C} + 9.2^\circ\text{C} = 109.2^\circ\text{C}$$

$$\Delta T_f = -1.86^\circ\text{C/m} \times 18.04 \text{ m} = -33.6^\circ\text{C}$$

$$T_f = 0^\circ\text{C} - 33.6^\circ\text{C} = -33.6^\circ\text{C}$$