Last name :_______________Given name :___________________________

Student number:______________________

Lab Section:________________________Lab TA: __________________

Chemistry 1311D
Test 1 V1
October 10, 2013

1. **(5 points)** Computer chips are made from silicon, which occurs in nature as silicon dioxide (sand). When silicon dioxide is heated to melting it reacts with carbon to form liquid silicon and carbon monoxide gas. If 155.8 kg of silicon dioxide, SiO_2, reacts with 78.3 kg of carbon, C(solid) to produce 66.1 kg of silicon, determine the theoretical yield and the percent yield for the reaction.

$SiO_2(s) + C(s) \rightarrow Si(l) + CO(g)$ (unbalanced)

$SiO_2(s) + 2C(s) \rightarrow Si(l) + 2CO(g)$

155.8 kg SiO_2; 60.084 g/mol; $n = \text{mass}/M = \frac{155.8\times10^3 g}{60.084 g/mol} = 2593$ moles

78.3 kg C; 12.011 g/mol; $n = \frac{78.3\times10^3 g}{12.011 g/mol} = 6519$ moles

66.1 kg Si; 28.086 g/mol

If all SiO_2 used: 2593 moles $SiO_2 \times \frac{1 Si}{1 SiO_2} = 2593$ moles Si

If all C(s) used: 6519 moles $\times \frac{1 Si}{2C} = 3260$ moles Si

∴ SiO_2 is limiting

Theoretical yield: 2593 moles $SiO_2 \times \frac{1 Si}{1 SiO_2} \times 28.086$ g/mol = <u>72.8 kg</u>

% yield = $\frac{66.1 kg}{72.8 kg} \times 100 = 90.8\%$

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VI

2.a) **(4 points)** The SO_2 present in air is mainly responsible for the acid rain phenomenon. The SO_2 concentration can be determined by reacting it with permanganate (MnO_4^-) in a potassium permanganate, $KMnO_4(aq)$, solution. Balance the following reaction:

$$SO_2(g) + MnO_4^-(aq) \rightarrow SO_4^{2-}(aq) + Mn^{2+}(aq)$$

+4 +7 +6 +2

$5(2H_2O + SO_2 \rightarrow SO_4^{2-} + 4H^+ + 2e)$

$2(MnO_4^- + 8H^+ + 5e \rightarrow Mn^{2+} + 4H_2O)$

$\cancel{10}\,8\,H_2O + 5SO_2 + \cancel{16H^+} + \cancel{10e} + 2MnO_4^- \rightarrow 5SO_4^{2-} + \cancel{20}\,4\,H^+ + \cancel{10e} + 2Mn^{2+} + \cancel{8H_2O}$

$2H_2O(l) + 5SO_2(g) + 2MnO_4^-(aq) \rightarrow 4H^+(aq) + 5SO_4^{2-}(aq) + 2Mn^{2+}(aq)$

b) **(4 points)** Calculate the number of grams of SO_2 in a sample of air if 7.37ml of 0.0800 M potassium permanganate, $KMnO_4(aq)$, solution are need to fully react with the SO_2.

$n_{MnO_4^-} = n_{KMnO_4} = [C]V = 0.0800\ \frac{moles}{l} \times 7.37\times10^{-3}\ l =$ moles

= XXXXXXXXXXXXXXXXXX

5.896 x 10^-4

$n_{SO_2} = n_{MnO_4^-} \times \frac{5\,SO_2}{2\,MnO_4^-} = 5.896\times10^{-}$ xx4 $\frac{5}{2} = 1.474\times10^{-3}$ moles

mass SO_2 = $n_{SO_2} \times \mathcal{M}_{SO_2} = 1.474\times10^{-3}$ moles $\times$ 64.064 g/mole

= 0.0944g

= 94.4 mg

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3. The odour from pineapple is due to the presence of the compound ethyl butyrate, which contains only carbon, hydrogen and oxygen. Combustion of 2.78 g of ethyl butyrate at 20 °C and 1 bar pressure produces 3.50 L of CO_2 (g) and 2.584 ml of H_2O(l). The density of water at 20 °C is 0.99820 g/ml.

a) **(2.5 points)** Determine the % weight of carbon in ethyl butyrate. mass C ← nC ← nCO_2

$n_{CO_2} = \frac{PV}{RT} = \frac{(1\ bar)(3.5L)}{0.08314\ \frac{bar\ L}{mol\ K}(293)} = 0.1437$ moles CO_2 = 0.1437 moles C

$m_C = 0.1437$ moles C × 12.011 g/mol = 1.73g

$\%wt = \frac{1.73g}{2.78g} \times 100 = 62.1\%$

b) **(2.5 points)** Determine the % weight of hydrogen in ethyl butyrate. $V_{H_2O} \rightarrow m_{H_2O} \rightarrow n_{H_2O} \rightarrow n_H \rightarrow m_H$

$m_{H_2O} = V \times d = 2.584\ ml \times 0.99820\ g/ml = 2.579g$

$n_{H_2O} = \frac{mass}{M} = \frac{2.579g}{18.015 g/mol} = 0.1432$ moles H_2O; $n_H = 2n_{H_2O} = 2 \times 0.1432 = 0.2863$ moles H

mass H = 0.2863 moles × 1.008 g/mol = 0.2886g

$\%wt = \frac{0.2886g}{2.78g} \times 100 = 10.4\%$

c) **(1 points)** Determine the % weight of oxygen in ethyl butyrate.

100 − 10.4 − 62.1 = 27.5% O

mass O = .275(2.78g) = 0.7645g

$nO = \frac{mass}{M} = \frac{0.7645g}{15.999 g/mol} = 0.04778$ moles

d) **(2 points)** What is the empirical formula for ethyl butyrate?

$C_{\frac{0.1437}{0.04778}} H_{\frac{0.2863}{0.04778}} O_{\frac{0.04778}{0.04778}}$: $C_{3.00}H_{5.99}O$ ≈ C_3H_6O

e) **(2 points)** Determine the molecular formula of ethyl butyrate given that the molar mass is 116.16 g/mol.

$Factor = \frac{M}{EF_{mass}} = \frac{116.16 g/mol}{58 g/mol} = 1.99 \approx 2$

$C_6H_{12}O_2$

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4. Consider the organic compounds acetylene, $C_2H_2(g)$ and benzene, $C_6H_6(l)$. Acetylene can be converted to benzene as shown below:

$$3C_2H_2(g) \rightarrow C_6H_6(l) \qquad \text{(RXN 4.1)}$$

a) **(1 point)** What are the empirical formulae for acetylene and benzene ?

CH

b) **(2 points)** What are the reactions for complete combustion of acetylene and benzene at 25 °C ?

$C_2H_2(g) + \frac{5}{2}O_2(g) \longrightarrow 2CO_2(g) + H_2O(l) \quad -1299.4 \frac{kJ}{mol}$

$C_6H_6(l) + \frac{15}{2}O_2(g) \longrightarrow 6CO_2(g) + 3H_2O(l) \quad -3267.4 \frac{kJ}{mol}$

c) **(3 points)** The enthalpy for complete combustion of acetylene is -1299.4 kJ/mol and of benzene is -3267.4 kJ/mol. Using this information and the standard heats of formation below determine the enthalpy of formation of acetylene and benzene and the enthalpy change for the formation of C_6H_6 from C_2H_2 (RXN 4.1 above).

$CO_2(g)$ Δ_fH = -393.5 kJ/mol $H_2O(g)$ Δ_fH = -241.8 kJ/mol
$CO_2(aq)$ Δ_fH = -412.9 kJ/mol $H_2O(l)$ Δ_fH = -285.8 kJ/mol

acetylene

$-1299.4 = \Delta_fH(H_2O(l)) + 2\Delta_fH(CO_2(g)) - \Delta_fH_{C_2H_2(g)}$
$= -285.8 + 2(-393.5)$
$\Delta_fH_{C_2H_2(g)} = -285.8 - 2(393.5) + 1299.4 = 226.6 \text{ kJ mol}^{-1}$

benzene $-3267.4 = 3\Delta_fH(H_2O) + 6\Delta_fH\,CO_2 - \Delta_fH\,C_6H_6$
$\Delta_fH_{C_6H_6} = 3(-285.8) + 6(-393.5) + 3267.4 = +49 \text{ kJ mol}^{-1}$

$3C_2H_2(g) \rightarrow C_6H_6(l)$

$\Delta_{RXN}H = \Delta_fH_{C_6H_6} - 3(\Delta_fH_{C_2H_2}) = 49 - (3(226.6)) = -630.8 \text{ kJ}$

d) **(2 points)** If the acetylene was converted to benzene under constant pressure conditions, would you expect $\Delta_{rxn}U$ to be more positive than, more negative than or equal to $\Delta_{rxn}H$? Explain briefly.

q_p rxn $= \Delta_{rxn}H = -630.8$ kJ

$w \longrightarrow$ g turns to l, compression, +ve

$\Delta U = q_p + w = (-ve) + (+ve)$

$\Delta_{rxn}U$ is more positive than q_p & $\Delta_{rxn}H$.

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5. **(4 points)** The reaction of 124 g of solid P_4 with 61.9 L of O_2 at 25 °C and 1 bar results in the formation of $P_4O_{10}(s)$. The reaction generates enough heat to raise the temperature of 1475 g of water from 19.0 °C to 39.0°C. Calculate the enthalpy of formation $P_4O_{10}(s)$. Some things you may (or may not) be interested in include: Heat capacity of liquid water is 4.18 J °C^{-1}g^{-1}; of ice 2.05 J °C^{-1} g^{-1}; of steam 1.996 J °C^{-1} g^{-1}; ΔH_{vap} 40.7 kJ mol^{-1}; ΔH_{fusion} = 6.0kJ mol^{-1}

$$P_4(s) + O_2(g) \rightarrow P_4O_{10}(s) \text{ (unbalanced)}$$

$$P_4(s) + 5O_2(g) \rightarrow P_4O_{10}(s)$$

124g P_4 $M = 123.8948$ g/mol $n_{P_4} = 124/123.8948 = 0.999$ moles $\rightarrow$ 0.999 moles P_4O_{10}

61.9L of O_2 @ 298K, 1 bar $n_{O_2} = \frac{PV}{RT} = \frac{1\text{bar}(61.9L)}{.08314 \frac{L\,bar}{mol\,K}(298)} = 2.498$ moles O_2

$n_{P_4O_{10}} = 2.498 \text{ moles } O_2 \times \frac{1 P_4O_{10}}{5 O_2}$

$= 0.4996$

$M_{H_2O} = 1475g$

$\Delta T = 20°C$

O_2 limiting!

$q_{H_2O} = mC\Delta T$

$q_{H_2O} = 1475g(4.18 \frac{J}{°Cg})(20°C)$

$= 123$ kJ For 0.4996 moles $P_4O_{10}(s)$ product.

$\Delta_f H_{P_4O_{10}} = -\frac{123 kJ}{0.4996 \text{ moles}} = -246.6$ kJ/mol

6. **(5 points)** A solution of hexane, C_6H_{14}, in heptane, C_7H_{16}, is prepared with a concentration of X_{hexane} = 0.20. Given the density of hexane, 0.6548 g/ml and of heptanes, 0.6840 g/ml determine the molality and molarity of the solution. Assume volume of the final solution is equal to volumes of components.

$X_{C_6} = 0.2$ moles

$d_{C_6} = 0.6548$ g/ml

$M_{C_6} = 86.172$ g/mol

mass $= n \times M = 0.2(86.172 g/mol)$
$= 17.2344g$

$V = \frac{mass}{d} = \frac{17.2344g}{.6548 g/ml}$

$= 26.32$ ml

$X_{C_7} = 0.8$ mole

$d_{C_7} = 0.6840g$

$M_{C_7} = 100.198$ g/mol

mass $= 0.8(100.198)$
$= 80.158g$

$V = \frac{80.158g}{0.6840}$

$= 117.19m$

molality $= \frac{n_{C_6}}{kg\ C_7}$

molarity $\frac{n_{C_6}}{V_{sol^n}}$

Molarity
$= \frac{0.2}{(26.32 + 117.19)\times 10^{-3} L}$
$= 1.39$ moles / l

Molality $= \frac{0.2}{80.158\times 10^{-3} kg}$
$= 2.5 \frac{moles}{kg\ C_7H_{16}}$

Bonus: What is the density of the solution ?

Density $= \frac{mass}{Volume} = \frac{17.23 + 80.16 \text{ g}}{26.32 + 117.19 \text{ ml}}$

$= 0.6786$ g/ml

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