

## YUSO 2017 CHEMISTRY LAB ANSWER KEY

Express All Answers to 3 Significant Figures

Thermodynamics (70 points)

1. (1 point each)

- i. B) Exothermic
- ii. B) Exothermic
- iii. A) Endothermic

2. (1 point each)

- i. A)  $\Delta S^0 > 0$
- ii. B)  $\Delta S^0 < 0$
- iii. A)  $\Delta S^0 > 0$

3. (8 points)

a. (4 points)

$$q = mC_p\Delta T.$$

$$m = 98. \text{ g} + 2.17 \text{ g} = 100.17 \text{ g}$$

$$\text{The specific heat of water is } C_p = 4.184 \frac{\text{J}}{\text{g}\cdot^\circ\text{C}} = 1 \frac{\text{cal}}{\text{g}\cdot^\circ\text{C}}.$$

$$\Delta T = T_f - T_i = 25.0^\circ\text{C} - 23.4^\circ\text{C} = 1.6^\circ\text{C}$$

$$q = 100. \text{ g} \times 4.184 \frac{\text{J}}{\text{g}\cdot^\circ\text{C}} \times 1.6^\circ\text{C} \approx 669 \text{ J} = 160. \text{ cal}$$

b. (4 points)

$$\text{Molar mass of NH}_4\text{NO}_3: 2 \times 14.01 \text{ g/mol} + 4 \times 1.008 \text{ g/mol} + 3 \times 16.00 \text{ g/mol} = 80.052 \text{ g/mol}$$

$$\text{Moles of NH}_4\text{NO}_3 \text{ used: } 2.17 \text{ g} / 80.052 \text{ g/mol} \approx 0.0271 \text{ mols of NH}_4\text{NO}_3$$

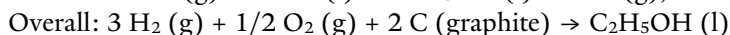
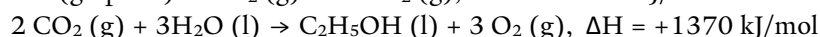
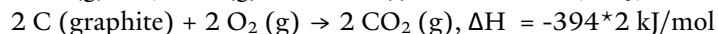
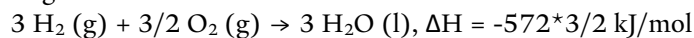
$$669 \text{ J} / 0.0271 \text{ mols} \approx 24700 \text{ J/mol} = 24.7 \text{ kJ/mol} = \Delta H$$

Since  $\Delta H > 0$ , the reaction is endothermic.

4. (12 points)

a. (4 points)

We rearrange the reactions:



$$\Delta H_f = (-572 \times 3/2 + -394 \times 2 + 1370) \text{ kJ/mol} = -277 \text{ kJ/mol}$$

b. (8 points)

$$\text{Molar mass of ethanol: } 2 \times 12.01 + 6 \times 1.008 + 16.00 = 46.068 \text{ g/mol}$$

$$\text{Moles of ethanol: } 20.17 \text{ g} \times 1 \text{ mol} / 46.068 \text{ g} = 0.4378103 \text{ mol ethanol}$$

$$\text{Moles of oxygen (use } PV=nRT) \text{ } n = PV/RT = 1.35 \text{ atm} \times 20.17 \text{ L} / (0.0821 \text{ atm}\cdot\text{L/mol}\cdot\text{K} \times 293 \text{ K}) = 1.132 \text{ mol O}_2$$

Since mols  $\text{O}_2$  / mols ethanol  $< 3$ , oxygen is limiting.

$$1.132 \text{ mol O}_2 \times 1 \text{ mol rxn} / 3 \text{ mol oxygen} \times -1370 \text{ kJ/mol} = -517 \text{ kJ} \rightarrow 517 \text{ kJ of heat released.}$$

5 (12 points)

a. (6 points)

$$50. g \times \left( 5.0^{\circ}\text{C} \times 2.06 \frac{\text{J}}{\text{g}\cdot\text{K}} + 333 \frac{\text{J}}{\text{g}} + 100^{\circ}\text{C} \times 4.184 \frac{\text{J}}{\text{g}\cdot\text{K}} + 2256 \frac{\text{J}}{\text{g}} + 5^{\circ}\text{C} \times 1.86 \frac{\text{J}}{\text{g}\cdot\text{K}} \right) = 151350 \text{ J} \approx 36200 \text{ calories}$$

b. (6 points)

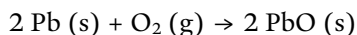
Heated lost by water = heat gained by ice. Let  $T_f$  be the final temperature in  $^{\circ}\text{C}$ .

$$75 \text{ g} \times 4.184 \frac{\text{J}}{\text{g}\cdot\text{K}} \times (55^{\circ}\text{C} - T_f) = 50. \text{ g} \times 5.0^{\circ}\text{C} \times 2.06 \frac{\text{J}}{\text{g}\cdot\text{K}} + 50. \text{ g} \times 333 \frac{\text{J}}{\text{g}} + 50. \text{ g} \times 4.184 \frac{\text{J}}{\text{g}\cdot\text{K}} \times T_f$$

Solving, we get:  $T_f = 0.180^{\circ}\text{C}$ 

6. (10 points)

a. (1 point)



b. (2 points)

$$\Delta H^{\circ} = \Delta H^{\circ}(\text{products}) - \Delta H^{\circ}(\text{reactants}) = (2 \times -219 - (2 \times 0 + 0)) \frac{\text{kJ}}{\text{mol}} = -438 \frac{\text{kJ}}{\text{mol}}$$

$$\Delta_{\text{rxn}}H^{\circ} = -438 \text{ kJ/mol}$$

c. (2 points)

Let  $x$  be the standard molar entropy of oxygen gas.

$$\Delta_{\text{rxn}}S^{\circ} = \Delta S^{\circ}(\text{products}) - \Delta S^{\circ}(\text{reactants}) = 2 \times 66.5 - 2 \times 64.8 - x = -201.7$$

$$x = S^{\circ} = 205.1 \text{ J/mol}\cdot\text{K}$$

d. (3 points)

$$\Delta G^{\circ} = \Delta H^{\circ} + T\Delta S^{\circ}$$

$$\Delta G^{\circ} = -376 \text{ kJ/mol, Spontaneous since } \Delta G^{\circ} < 0$$

e. (2 points)

No, since  $\Delta_{\text{rxn}}H^{\circ} < 0$  and  $\Delta_{\text{rxn}}S^{\circ} < 0$ .

7. (10 points)

a. (Write the correct choice, 2 points)

 $\Delta_{\text{rxn}}H^{\circ}$  is positive and  $\Delta_{\text{rxn}}S^{\circ}$  is negative

b. (4 points)

$$\text{Use the equation: } K_p = e^{-\frac{\Delta G}{RT}}$$

$$\text{At } 25^{\circ}\text{C} = 298 \text{ K, } K_p = 749$$

$$\text{At } 1002^{\circ}\text{C} = 1275 \text{ K, } K_p = 3.16 \times 10^{-31}$$

Most product favored at  $25^{\circ}\text{C}$  since largest  $K_p$  value.

8. (16 points)

a. (6 points)

We use:  $\ln(P_{\text{vap}}) = -\frac{\Delta H_{\text{vap}}}{R} \frac{1}{T} + \ln(A)$  and then apply a linear regression (using temperature in Kelvin).

$$\text{From linear regression, } m = -\frac{\Delta H_{\text{vap}}}{R} = -4605.717 \text{ and } b = \ln(A) = 20.29$$

b. (2 points)

$$-\frac{\Delta H_{\text{vap}}}{R} = -4605.717 \text{ so } \Delta H_{\text{vap}} = 38.28 \text{ kJ/mol}$$

c. (4 points)

Plug values from parts (a) and (b) and solve.

$$\ln(780) = -38.28 \frac{\text{kJ}}{\text{mol}} \div \left(8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}}\right) \times \frac{1}{T} + 20.295$$

$$T = 337.8 \text{ K, BP} \approx 65^\circ\text{C}$$

d. (4 points)

At the boiling point,  $\Delta G = \Delta H - T\Delta S = 0$

$$\text{So } \Delta S^\circ = 38.28 \frac{\text{kJ}}{\text{mol}} \div 337.8 \text{ K} \approx 113 \frac{\text{J}}{\text{mol} \cdot \text{K}}$$

### Gases (70 points)

1. (1 point each)

- decreases
- increases
- no effect

2.

- (3 points) A: gas, B: liquid, C: solid
- The liquid state is less dense than the solid phase because at constant temperature, the solid state (C) always exist at a higher pressure than the liquid state (B). This can be observed by drawing vertical lines through the phase diagram; for any of these constant temperature lines, the solid phase region is always higher on the pressure scale than the liquid phase. Higher pressures at constant temperature result in higher densities.

3. (8 points)

a. (4 points)

According to Graham's Law of Effusion,  $\text{rate}_1/\text{rate}_2 = \sqrt{M_2/M_1}$ .

$$\text{rate}_{\text{gas}}/\text{rate}_{\text{H}_2} = \sqrt{(2 \times 1.008/M_{\text{gas}})} = 0.169$$

$$M_{\text{gas}} = 70.90 \text{ g/mol}$$

$$\text{Since the gas is diatomic, } M_{\text{element}} = 70.90/2 = 35.45 \text{ g/mol}$$

This is chlorine gas.

b. (4 points)

$$PV = nRT$$

$$PV = (m/M)RT$$

$$PM = (m/V)RT = \rho RT \text{ where } \rho = \text{density}$$

$$\rho = (PM)/(RT) = (2.5 \times 70.90)/(0.0821 \times (25+273)) = 7.25 \text{ g/L}$$

4. (10 points)

$$\text{moles of water vapor initially present: } (92.5/760)(40) = n(0.0821)(50+273)$$

$$n = 0.184 \text{ mol water}$$

Water and CO react in a 1:1 ratio, and  $0.184 < 0.2$ , so water is the limiting reagent.

0.184 mol H<sub>2</sub> gas produced

$$P = nRT/V = 0.184(0.0821)(50+273)/40 = 0.122 \text{ atm}$$

5. (10 points)

Sphere with radius of 5 cm has volume of  $\frac{4}{3}\pi(20)^3 = 33510.322 \text{ cm}^3 = 33.510 \text{ L}$

This volume corresponds to  $n = PV/(RT) = 5(33.510)/(0.0821(25+273)) = 6.848 \text{ mol}$  of gas

Rate of effusion of  $\text{H}_2 = 1.5 \text{ mol/minute}$

Rate of effusion of He =  $\text{rate}_{\text{H}_2} * \sqrt{M_{\text{H}_2}/M_{\text{He}}} = 1.5 * \sqrt{2*1.008/4.003} = 1.064 \text{ mol/minute}$

Total gas effusion rate =  $1.5 + 1.064 = 2.564 \text{ mol/minute}$

$6.848 \text{ mol} / (2.564 \text{ mol/minute}) = 2.670 \text{ minutes}$

6. (15 points)

a. (4 points)

Ammonia has the larger  $a$  value because the expression  $an^2/V^2$  helps correct for the fact that attractive forces between gas particles will curve individual particles' paths, therefore delaying their impact with the container walls and decreasing the overall pressure. Thus,  $a$  represents the relative strength of the attractive forces between the gas particles. Since ammonia experiences greater intermolecular attractions than methane does due to dipole-dipole interactions, its  $a$  value is greater.

b. (4 points)

The expression  $-bn$  corrects for the fact that gas molecules have finite volume, therefore decreasing the effective volume of the container. Molecules with greater volume thus correspond to greater  $b$  values in order to account for the increased volume. For monoatomic gases, volume increases with molecular mass, so  $b$  must increase with molecular mass as well.

c. (7 points)

Ideal Gas Law:  $T = PV/(nR) = 100*3/(30*0.0821) = 121.803 \text{ K}$

Van der Waals:  $T = (P + an^2/V^2)(V - bn)/(nR) = (100 + 1.382(30)^2/3^2)(3 - 0.03186*30)/(30*0.0821) = 197.697 \text{ K}$

$(T_{\text{Van der Waals}} - T_{\text{Ideal}})/T_{\text{Ideal}} * 100\% = 62.309\%$

7. (15 points)

a. (5 points)

$1 \text{ mol CClF}_2 \rightarrow 1 \text{ mol Cl(g)} \rightarrow 1 \text{ mol ClO produced}$

$P_{\text{ClO}} = nRT/V = 1*0.0821(27+273)/50 = 0.493 \text{ atm}$

b. (10 points)

$5 - 1 = 4 \text{ mol O}_3$  remaining after part (a)

$20\% * 4 = 0.8 \text{ mol}$  of  $\text{O}_3$  dissociates to form 0.8 mol  $\text{O}_2$  + 0.8 mol O radical

1 mol ClO reacting with 0.8 mol O radical  $\rightarrow$  0.8 mol  $\text{O}_2$  produced

1 mol  $\text{O}_2$  produced in part (a)

total moles of  $\text{O}_2 = 1 + 0.8 + 0.8 = 2.6 \text{ mol O}_2$

$P_{\text{O}_2} = nRT/V = 2.6*0.0821(27+273)/50 = 1.281 \text{ atm}$