CHM2132 Midterm 1
Friday October 9th, 2015

Name: ________________________________

Student #: ________________________________

This is a closed book exam with no notes allowed.
Calculators are permitted.
Show all your work.
Remember to include units in all your calculations**.**
<u>Marks will be deducted if units are not shown in your final answer.</u>
You will find the equations, data and constants on the last page. You may rip this page off of the midterm and use it to cover your work during the test.

Q1: __________/6

Q2: __________/11

Q3: __________/9

Q4: __________/14

Total = __________/40

1. The following statements are **FALSE**. **Choose 3 of the 4 statements below** and:

(i) Change the sentence so that it becomes a correct statement.

(ii) In one sentence explain why the statement was incorrect. In some cases you might use an equation to help your explanation. (6 marks)

a) To calculate the work done on a warm ideal gas trapped in a balloon after it is put in the fridge, it is not possible to use $w = -nRT\ln\left(\frac{V_2}{V_1}\right)$ if the volume change is very slow.

The temperature of the gas will change, but the work equation given is for a **reversible, isothermal** process. The work equation to use in this case is $w = -p_{ext}\Delta V$

b) The standard state of H_2O is ~~solid~~ liquid.

When the temperature is not specified, we assume standard temperature of 298.15 K. At this temperature, the most stable state of water is liquid.

c) ~~No~~ heat is absorbed by air trapped in a sealed bottle when the bottle is opened if the temperature of the air outside the room is the same as the temperature of the air in the bottle.

When the bottle is opened, the gas that was trapped inside diffuses into the room – it has to do work to carry out this expansion against 1 atm of pressure. Since this process is isothermal, the gas gets its energy to do the work by absorbing heat.

$$(\Delta U = 0 \therefore q = -w)$$

d) The partial derivative $\left(\frac{\partial V}{\partial T}\right)_{n,p}$ can not be used to calculate the change in volume for an ideal gas that is compressed in a thermally insulated balloon.

Compression of a thermally insulated balloon changes the pressure and temperature of the gas. To calculate a change in volume it would be necessary to use:

$$dV = \left(\frac{\partial V}{\partial T}\right)_{n,p} dT + \left(\frac{\partial V}{\partial p}\right)_{n,T} dp$$

Note that if you wanted to calculate the change in volume for an ideal gas in a constant pressure process:

$dV = \left(\frac{\partial V}{\partial T}\right)_{n,p} dT = \frac{nR}{p} dT$, which after integration becomes: $\Delta V = \frac{nR}{p}\Delta T$

Also, note that thermally insulated does **not** mean $\Delta T = 0$.

2. A 1.60 mol sample of an ideal gas with $C_{V,m} = 5/2\ R$, at 2.82 bar, 340.0 K is expanded adiabatically against an external pressure of 0.230 bar until the final pressure is 0.250 bar.

a) What is the final temperature of this gas? (4 marks)

$$\Delta U = w \quad 0.5$$

$$nC_{V,m}\Delta T = -p_{ext}\Delta V \quad 1$$

0.5

$$n\frac{5}{2}R(T_2 - T_1) = -p_{ext}\left(\frac{nRT_2}{p_2} - \frac{nRT_1}{p_1}\right)$$

SUB IN IDEAL GAS LAW ①

$$\frac{5}{2}(T_2 - T_1) = -p_{ext}\left(\frac{T_2}{p_2} - \frac{T_1}{p_1}\right)$$

$$T_2 = \underbrace{\frac{\left(\frac{5}{2}+\frac{p_{ext}}{p_1}\right)T_1}{\left(\frac{5}{2}+\frac{p_{ext}}{p_2}\right)}} = \frac{\left(\frac{5}{2}+\frac{0.230\text{ bar}}{2.82\text{ bar}}\right)340\text{ K}}{\left(\frac{5}{2}+\frac{0.230\text{ bar}}{0.250\text{ bar}}\right)} = 257\text{ K}$$

CORRECT SUBSTITUTION

CORRECT REARRANGEMENT 0.5

b) What is the total work done in this process? (~~3~~ 2 marks)

①

$$w = nC_{V,m}\Delta T = n\frac{5}{2}R(T_2 - T_1)$$

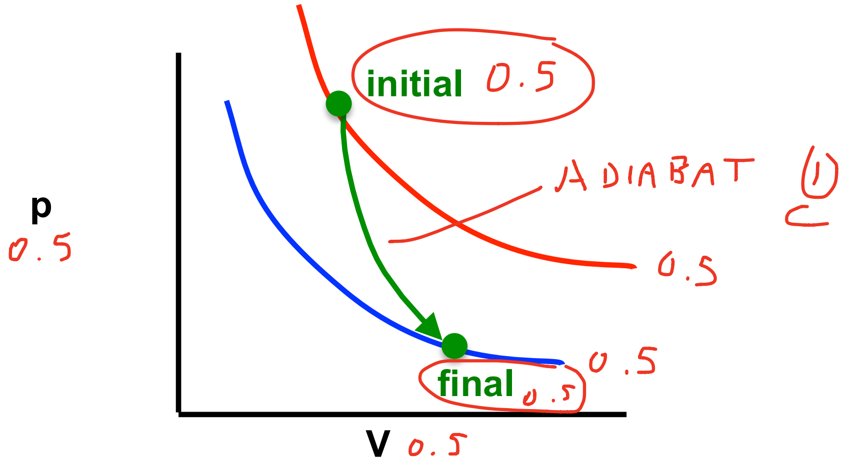
0.5

$$= (1.60\text{ mol})\left(\tfrac{5}{2}\right)\left(8.314\text{ J K}^{-1}\text{ mol}^{-1}\right)(257\text{ K} - 340\text{ K})$$

$$= -2.76\text{ kJ}$$

CORRECT R 0.5

c) Draw a reversible adiabatic expansion on a pressure-volume diagram. Be sure to label the axes with p and V, show isotherm(s) and label initial and final states. (4 marks)



3. A mixture of H_2 and NH_3 in a 500.0 mL vessel at 0.00°C has a pressure of 1.00 atm. The mixture is cooled to 77.0 K, which causes the ammonia to freeze. The remaining gas is removed from the vessel, which is then warmed up to 25.0°C to give a pressure of 0.344 atm.

a) What is the mole fraction of NH_3 in the original mixture? (4 marks)

$$\chi_{NH_3} = \frac{n_{NH_3}}{n_T} \quad ①$$

① ①

$$= \frac{\dfrac{p_{NH_3}V}{RT_{final}}}{\dfrac{p_T V}{RT_{initial}}} = \frac{\dfrac{p_{NH_3}}{T_{final}}}{\dfrac{p_T}{T_{initial}}}$$

$$= \frac{\dfrac{0.344\text{ atm}}{298.15\text{ K}}}{\dfrac{1.00\text{ atm}}{273.15\text{ K}}} = 0.315\text{ atm}$$

①
CORRECT SUBSTITUTION

b) Is the internal energy of NH_3 at the end of the process higher, lower, or equal to, its internal energy at the end of the process? Briefly explain your answer. (2 marks)

0.5 0.5

The internal energy of NH_3 is higher because it is at a higher temperature. (Its internal energy is not affected by the H_2, assuming ideal gas behavior.)

$\Delta U = nC_{v,m}\Delta T \quad \therefore \Delta T > 0$ ①

$\therefore \Delta U > 0$

c) If H_2 and NH_3 undergo attractive interactions, would the original gas mixture release heat if it was allowed to undergo an isothermal expansion into a completely empty 1 L container? Why or why not? (3 marks)

①

If container is completely empty, then $p_{ext} = 0$, and no work is required for the expansion. For an ideal gas, no heat would be required, but in this case attractive interactions must be lost for the expansion. Therefore energy is required, and heat would be absorbed.

① ①

4.

ΔH_R^o (kJ mol^{-1})		$C_{p,m}$ (J mol^{-1} K^{-1})	
$H_2(g)+\frac{1}{2}O_2(g)\rightarrow H_2O(g)$	-242	$H_2(g)$	28.8
$\frac{1}{2}H_2(g)+\frac{1}{2}O_2(g)\rightarrow OH(g)$	40.0	$O_2(g)$	29.4 $32.83-0.00363\frac{T}{K}$
$H_2(g)\rightarrow 2H(g)$	426	$H(g)$	20.8
$O_2(g)\rightarrow 2O(g)$	498	$O(g)$	21.9
		$OH(g)$	29.9
		$H_2O(g)$	33.6

Use the data in the table (all at 298.15 K) to answer the following questions about this reaction:

$$H(g)+OH(g)\rightarrow H_2O(g)$$

a) Calculate ΔH_R^o at 298.15 K. You must show your work using balanced chemical equations for full marks. (~~3~~ marks)
4

$\cancel{H_2}(g)+\frac{1}{2}\cancel{O_2}(g)\rightarrow H_2O(g)$ $\qquad \Delta H_R^o=-242$ kJ mol^{-1} ①

$OH(g)\rightarrow \frac{1}{2}\cancel{H_2}(g)+\frac{1}{2}\cancel{O_2}(g)$ $\qquad \Delta H_R^o\times -1=-40.0$ kJ mol^{-1} ①

$\underline{H(g)\rightarrow \frac{1}{2}\cancel{H_2}(g)}$ $\qquad \underline{\Delta H_R^o\times -1\times\frac{1}{2}=-426\times\frac{1}{2}\text{ kJ mol}^{-1}=-213\text{ kJ mol}^{-1}}$ ①

$H(g)+OH(g)\rightarrow H_2O(g)$ $\qquad \Delta H_R^o=(-242-40.0-213)$ kJ mol^{-1} $=-495$ kJ mol^{-1} ①

b) Based on your answer in a), is this reaction endothermic or exothermic. (1 mark)

Exothermic

c) Calculate ΔU_R^o at 298.15 K. (3 marks)

$$\Delta H_R^o = \Delta U_R^o + \Delta\left(pV\right) \quad ①$$

$$\Delta U_R^o = \Delta H_R^o - \Delta\left(pV\right)$$

$$= \Delta H_R^o - \Delta\left(nRT\right)$$

Since this is an isothermal reaction (constant T):

$$\Delta U_R^o = \Delta H_R^o - \Delta nRT \quad ①$$

$$\Delta n = n_{\text{gas, products}} - n_{\text{gas, reactants}} = 1 - 2 = -1 \quad 0.5$$

$$\Delta U_R^o = -495 \text{ kJ mol}^{-1} + (1)\left(8.314 \text{ J K}^{-1} \text{ mol}^{-1}\right)\left(298.15 \text{ K}\right)\underline{\left(10^{-3} \text{ kJ J}^{-1}\right)}$$

$$= -492 \text{ kJ mol}^{-1}$$

0.5

d) Calculate ΔH_R^o at 400.15 K. (3 marks)

$$\Delta H_R^o\left(400.15 \text{ K}\right) = \Delta H_R^o + \Delta C_{p,m}\Delta T \quad ①$$

$$= \Delta H_R^o + \left(C_{p,m}\left(\text{H}_2\text{O}_{(g)}\right) - C_{p,m}\left(\text{H}_{(g)}\right) - C_{p,m}\left(\text{OH}_{(g)}\right)\right)\Delta T$$

$$= -495 \text{ kJ mol}^{-1} + \underline{\left(33.6 - 20.8 - 29.9\right)} \text{ J K}^{-1} \text{ mol}^{-1}\left(400.15 \text{ K} - 298.15 \text{ K}\right)\underline{\left(10^{-3} \text{ kJ J}^{-1}\right)}$$

$$= -497 \text{ kJ mol}^{-1}$$

① (0.5)

CORRECT SUBS. (0.5)

e) Calculate the heat required to raise the temperature of $O_2(g)$ from 298.15 K to 400.15 K under standard conditions. (4 marks)

$$q_p = \Delta H = \int Cp\, dT$$

$$= \int_{T_1}^{T_2}\left[\left(32.83 - 0.00363\frac{T}{K}\right)\text{J K}^{-1} \text{ mol}^{-1}\right]dT \quad ①$$

Using the formula: $\int x^n\, dx = \frac{1}{n+1}x^{n+1} + c$

$$\Delta H = \left|\left(32.83T - 0.00363\frac{1}{2}\frac{T^2}{K}\right)\text{J K}^{-1} \text{ mol}^{-1}\right|_{T_1}^{T_2}$$

$$= \left[\overset{①}{\underline{32.83\Delta T}} - 0.00363\overset{①}{\underline{\frac{1}{2K}\left(T_2^2 - T_1^2\right)}}\right]\text{J K}^{-1} \text{ mol}^{-1}$$

$$= \left[32.83\left(400.15 \text{ K - } 298.15 \text{ K}\right) - 0.00363\frac{1}{2K}\left(\left(400.15 \text{ K}\right)^2 - \left(298.15 \text{ K}\right)^2\right)\right]\text{J K}^{-1} \text{ mol}^{-1}$$

$$= 3.2 \text{ kJ mol}^{-1}$$

SUBSTITUTIONS

①

Constants and Data

R = 8.314 J K^{-1} mol^{-1} = 0.08206 L atm mol^{-1} K^{-1} = 0.08314 L bar mol^{-1} K^{-1}
1 L = 10^{-3} m^{3} 1 kJ = 1000 J 1 atm = 101325 Pa
1 bar = 10^{5} Pa 1 L atm = 101.325 J 1 J = 1 kg m^{2} s^{-2} 1 Pa = 1 kg m^{-1} s^{-2}

Equations

$$\boxed{pV = nRT} \qquad \boxed{p = \frac{nRT}{V - nb} - a\left(\frac{n}{V}\right)^2} \qquad \boxed{p_\mathrm{A} = x_\mathrm{A} p_\mathrm{T}} \qquad \boxed{x_\mathrm{A} = \frac{n_\mathrm{A}}{n_\mathrm{Total}}}$$

$$\boxed{\Delta U = w + q} \qquad \boxed{w = \int_{x_1}^{x_2} F \cdot dx} \qquad \boxed{w = \int_0^Q \phi \cdot dQ'} \qquad \boxed{w = -\int_{V_1}^{V_2} p_{ext}\, dV}$$

$$\boxed{C_p - C_V = nR} \qquad \boxed{\Delta U = \int_{T_1}^{T_2} C_V\, dT} \qquad \boxed{\Delta H = \int_{T_1}^{T_2} C_p\, dT} \qquad \boxed{H = U + pV}$$

$$\boxed{\pi_T = \left(\frac{\partial U}{\partial V}\right)_T} \qquad \boxed{p_1 V_1^\gamma = p_2 V_2^\gamma \quad \gamma = \frac{C_p}{C_V}} \qquad \boxed{\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{(\gamma - 1)}}$$

$$\boxed{\Delta H_R^\circ = \sum_{\text{Products}} v\Delta H_f^\circ - \sum_{\text{Reactants}} v\Delta H_f^\circ} \qquad \boxed{\Delta H_{r,T}^\circ = \Delta H_{r,298.15\,\mathrm{K}}^\circ + \int_{T_1}^{T_2} \Delta C_p\left(T'\right) dT'}$$

$$\boxed{\Delta C_p\left(T'\right) = \sum_i v_i C_{p,i}\left(T'\right)} \qquad \boxed{\int x^n\, dx = \frac{1}{n+1} x^{n+1} + c} \qquad \boxed{\int \frac{dx}{x} = \ln x + c} \qquad \boxed{\frac{dx^n}{dx} = \frac{1}{n} x^{n-1}}$$