CHM2132 Midterm 1
Friday October 7th, 2016

Name: ________________________________

Student #: ________________________________

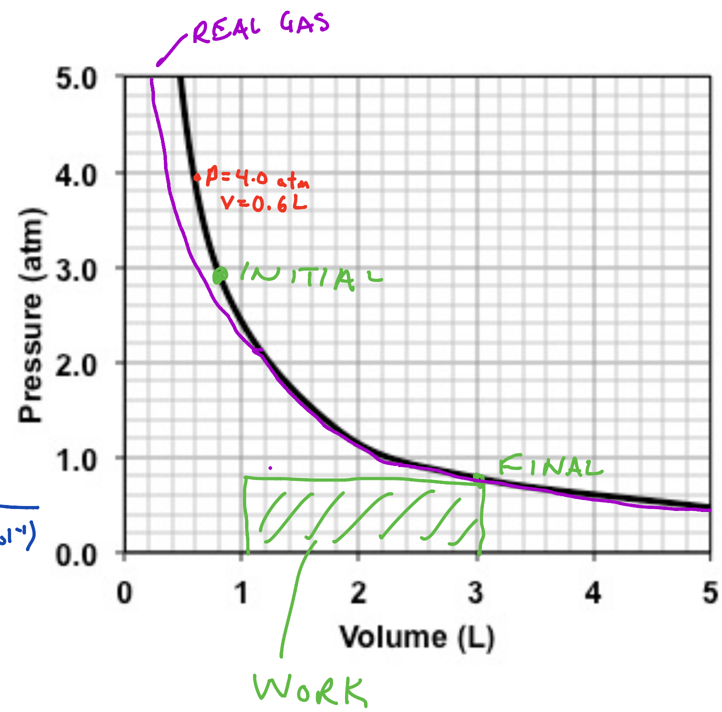
This is a closed book exam with no notes allowed.
Calculators are permitted.
Show all your work.
Remember to include units in all your calculations**.**
<u>Marks will be deducted if units are not shown in your final answer.</u>
You will find the equations, data and constants on the last page. You may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

Q1: __________/20 Q2: __________/13 Q3: __________/6

Q4: __________/6

Total = __________/45

Question 1
The graph shown on the right is an isotherm for 0.050 mol of an ideal gas.



a) What is the temperature of this gas? (2 marks)

$$T = \frac{pV}{nR}$$

$$= \frac{(4.0\ \text{atm})(0.6\ \text{L})}{(0.050\ \text{mol})(0.08206\ \text{L}\cdot\text{atm}\cdot\text{K}^{-1}\text{mol}^{-1})}$$

$$= 580\ \text{K}$$

b) On the graph above, draw the process that corresponds to an irreversible isothermal expansion from 1 L to 3 L. Label the initial state and the final state on the graph. (No numbers are required.) Shade the area that corresponds to the work of this process. (2 marks)

c) Calculate the work done during this process. (2 marks)

$$W = -p_{ext}\,\Delta V$$

$$= -(0.8\ \text{atm})(101325\ \text{Pa}\ \text{atm}^{-1})(3\text{L}-1\text{L})(10^{-3}\ \text{m}^3\text{L}^{-1})$$

$$= -160\ \text{J}$$

d) Is the gas doing the work, or is work being done on the gas? (1 mark)

$\because$ GAS IS EXPANDING $w<0$, GAS IS DOING WORK

e) What is ΔU for this process? (1 mark)

$\Delta T = 0$

$\therefore \Delta U = 0$

f) What is q for this process? (1 mark)

$q = -w$
$= 160\ \text{J}$

g) Suppose the expansion of this gas from 1 L to 3 L was done adiabatically against a constant external pressure. What will happen to the temperature of the gas? Provide a one-sentence explanation for your answer. (2 marks)

IF THE EXPANSION IS ADIABATIC ($q=0$) THEN GAS TEMPERATURE WILL DECREASE. THE ENERGY NEEDED FOR THE GAS TO DO WORK COMES FROM THE GAS ITSELF, AND SO THE DECREASE IN ENERGY IS REFLECTED BY THE DECREASE IN TEMPERATURE.

($\Delta U = w$, $w<0$ $\therefore \Delta U = C_v \Delta T < 0$ $\therefore \Delta T < 0$)

h) On the graph on the previous page, sketch an approximate isotherm that you might expect to see for a real gas with strong attractive intermolecular interactions at high pressures. (2 marks)

i) If the real gas from part h) (i.e. with attractive intermolecular interactions) was allowed to expand against a vacuum in a vessel that was submerged in a water bath, would you expect the temperature of the water to go up or down? Briefly explain why. (3 marks)

TEMPERATURE OF THE WATER BATH SHOULD DECREASE. ENERGY IS REQUIRED FOR THE GAS TO EXPAND EVEN THOUGH FOR AN IDEAL GAS $w=0$ FOR EXPANSION AGAINST A VACUUM. ATTRACTIVE INTERACTIONS REQUIRE ENERGY TO BE DISRUPTED FOR THE REAL GAS – IN THIS CASE THE ENERGY WOULD COME FROM THE WATER BATH, DECREASING ITS TEMPERATURE.

j) Give an equation for the slope of a tangent to the isotherm drawn in a pressure versus volume graph like the one shown on the previous page. (The *final* equation should not contain a derivative.) (4 marks)

$$\left(\frac{\partial p}{\partial V}\right)_{T,n} = \left(\frac{\partial \frac{nRT}{V}}{\partial V}\right)_{T,n}$$

$$= nRT\left(\frac{\partial V^{-1}}{\partial V}\right)_{T,n}$$

$$= \frac{-nRT}{V^2}$$

Question 2

Answer the following questions for the reaction:

$$2\,B(s) + 3/2\,O_2\,(g) \rightarrow 2\,B_2O_3(s)$$

Physical Property (at 298 K)	Value
ΔH_R^o for $B_2O_3(s) + 3\,H_2O\,(g) \rightarrow 3\,O_2(g) + B_2H_6(g)$	2035.1 kJ mol^{-1}
$\Delta H_f^o\left(B_2H_6(g)\right)$	36.3 kJ mol^{-1}
$\Delta H_f^o\left(H_2O(l)\right)$	-285.8 kJ mol^{-1}
$\Delta H_{vap}^o\left(H_2O\right)$	40.7 kJ mol^{-1}
$C_{p,m}\left(B(s)\right)$	11.081 J K^{-1} mol^{-1}
$C_{p,m}\left(B_2O_3(s)\right)$	66.836 J K^{-1} mol^{-1}
$C_{p,m}\left(O_2(g)\right)$	29.355 J K^{-1} mol^{-1}

a) Calculate ΔH_R^o at 298 K using the data provided in the table. You must show your work with balanced chemical equations for full marks. (5 marks)

kJ mol^{-1}

$\cancel{B_2H_6}_{(g)} + \overset{3/2}{\cancel{3}}\,O_{2(g)} \rightarrow B_2O_{3(s)} + 3\,\cancel{H_2O}_{(g)}$ 2035.1×-1

$2B_{(s)} + 3\,\cancel{H_2}_{(g)} \rightarrow \cancel{B_2H_6}_{(g)}$ 36.3

$3\cancel{H_2O}_{(l)} \rightarrow 3\,\cancel{H_2}_{(g)} + 3\times\cancel{\tfrac{1}{2}}\,O_{2(g)}$ $-285.8 \times (-1) \times (3)$

$3\cancel{H_2O}_{(g)} \rightarrow 3\,\cancel{H_2O}_{(l)}$ $40.7 \times (-1) \times (3)$

$2B_{(s)} + \tfrac{3}{2}O_{2(g)} \rightarrow B_2O_{3(s)}$ -1263.4 kJ mol^{-1}

b) Calculate ΔU_R^o at 298 K. (4 marks)

$\Delta H_R^o = \Delta U_R^o + \Delta(pV) = \Delta U_R^o + \Delta(nRT) = \Delta U_R^o + \Delta n RT$

$\Delta n = n_{g,PRODUCTS} - n_{g,REACTANTS}$

$= 0 - \frac{3}{2} = -1.5$

$\Delta U_R^o = \Delta H_R^o - \Delta n RT$

$= -1263.5\,\frac{kJ}{mol} - (-1.5)(8.314\ J\,K^{-1}\,mol^{-1})(298\,K)(10^{-3}\,kJ/J)$

$= -1259.8\,\frac{kJ}{mol}$

c) Calculate ΔH_R^o at 450 K. (4 marks)

$$\Delta H_R^\circ(450\,\text{K}) = \Delta H_R^\circ(298\,\text{K}) + \int_{298\,\text{K}}^{450\,\text{K}} \Delta C_{p,m}(T')\,dT$$

$$= \Delta H_R^\circ(298\,\text{K}) + \Delta C_p \Delta T$$

$$= \Delta H_R^\circ(298\,\text{K}) + [C_{p,m}(B_2O_{3(s)}) - 2C_{p,m}(B_{(s)}) - \tfrac{3}{2}C_{p,m}(O_{2(g)})]\,\Delta T$$

$$= -1263.4\,\frac{\text{kJ}}{\text{mol}} + [66.836 - 2(11.081) - \tfrac{3}{2}(29.355)](\text{J K}^{-1}\text{mol}^{-1})(450\,\text{K} - 298\,\text{K})(10^{-3}\,\tfrac{\text{kJ}}{\text{J}})$$

$$= -1263.3\,\frac{\text{kJ}}{\text{mol}}$$

Question 3 (6 marks)
State all the conditions (e.g. isothermal, adiabatic, a constant value for a variable etc.) that are required to use each of the following equations:

a) $\dfrac{T_2}{T_1} = \left(\dfrac{V_1}{V_2}\right)^{(\gamma-1)}$ ADIABATIC, REVERSIBLE, (IDEAL GAS)

b) $q = \Delta H$ CONSTANT PRESSURE

c) $w = -nRT\ln\left(\dfrac{V_2}{V_1}\right)$ ISOTHERMAL, REVERSIBLE

d) $\Delta U = nC_{V,m}\Delta T$ $C_{V,m}$ IS TEMPERATURE INDEPENDENT (CONSTANT $C_{V,m}$)

Question 4.

In San Francisco, there is a chain of boutique ice cream parlours that use liquid nitrogen to make individual servings of ice cream as you wait. The founder built this ice cream empire on her knowledge of the physical properties of liquid nitrogen and thermodynamics.

Some of the data that might have been useful in the design of her ice cream makers include:

$\Delta H^o_{vap}(N_2) = 5.56 \text{ kJ mol}^{-1}$ $\quad C_{p,m}(N_2(l)) = 56.3 \text{ J K}^{-1} \text{ mol}^{-1}$ $\quad C_{p,m}(N_2(g)) = 29.1 \text{ J K}^{-1} \text{ mol}^{-1}$

a) How much heat is required to transform 1.75 mol of liquid nitrogen at its boiling point (-196 °C) into a gas at the ideal serving temperature of ice cream (-15 °C)? (4 marks)

$$q = q_{VAP} + q_{\Delta T}$$

$$= n\Delta H_{vap} + nC_{p,m}\Delta T$$

$$= (1.75 \text{ mol})(5.56 \text{ kJ mol}^{-1}) + (1.75 \text{ mol})(29.1 \text{ J K}^{-1} \text{ mol}^{-1})(-15°C - (-196°C)) \tfrac{K}{°C} \left(10^{-3} \tfrac{kJ}{J}\right)$$

$$= 9.73 \text{ kJ} + 9.21 \text{ kJ}$$

$$= 18.9 \text{ kJ}$$

b) How many moles of liquid nitrogen would be required to make one serving of ice cream, given that approximately 110 kJ of heat must be removed from the cream in this process? (2 mark)

FROM PEVIOUS PART, WE CAN CALCULATE HEAT ABSORBED BY N_2 PER MOL OF N_2

$$\Delta H_m = \frac{q_N}{n_{N_2}} = \frac{18.9 \text{ kJ}}{1.75 \text{ mol } N_2} = 10.8 \frac{\text{kJ}}{\text{mol } N_2}$$

HEAT TO BE REMOVED $= q_{REMOVED} = \Delta H_{m,N_2} \, n_{N_2}$

$$\therefore n_{N_2} = \frac{q_{REMOVED}}{\Delta H_{m,N_2}} = \frac{110 \text{ kJ}}{10.8 \text{ kJ/mol } N_2}$$

$$= 10 \text{ mol}$$

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

$$\boxed{pV = nRT}$$

$$\boxed{p = \frac{nRT}{V - nb} - a\left(\frac{n}{V}\right)^2}$$

$$\boxed{p_\mathrm{A} = x_\mathrm{A} p_\mathrm{T}}$$

$$\boxed{x_\mathrm{A} = \frac{n_\mathrm{A}}{n_\mathrm{Total}}}$$

$$\boxed{\Delta U = w + q}$$

$$\boxed{w = \int_{x_1}^{x_2} F \cdot dx}$$

$$\boxed{w = \int_0^Q \phi \cdot dQ'}$$

$$\boxed{w = -\int_{V_1}^{V_2} p_{ext}\, dV}$$

$$\boxed{C_p - C_V = nR}$$

$$\boxed{\Delta U = \int_{T_1}^{T_2} C_V\, dT}$$

$$\boxed{\Delta H = \int_{T_1}^{T_2} C_p\, dT}$$

$$\boxed{H = U + pV}$$

$$\boxed{\pi_T = \left(\frac{\partial U}{\partial V}\right)_T}$$

$$\boxed{p_1 V_1^\gamma = p_2 V_2^\gamma \quad \gamma = \frac{C_p}{C_V}}$$

$$\boxed{\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{(\gamma - 1)}}$$

$$\boxed{\Delta H_R^\circ = \sum_{\text{Products}} v\Delta H_f^\circ - \sum_{\text{Reactants}} v\Delta H_f^\circ}$$

$$\boxed{\Delta H_{r,T}^\circ = \Delta H_{r,298.15\,\mathrm{K}}^\circ + \int_{T_1}^{T_2} \Delta C_p(T')\, dT'}$$

$$\boxed{\Delta C_p(T') = \sum_i v_i C_{p,i}(T')}$$

$$\boxed{\int x^n\, dx = \frac{1}{n+1} x^{n+1} + c}$$

$$\boxed{\int \frac{dx}{x} = \ln x + c}$$

$$\boxed{\frac{dx^n}{dx} = \frac{1}{n} x^{n-1}}$$