

CHM2132 Midterm 1
Friday October 4th, 2019

Name: _____

Student #: _____

- This is a closed book exam with no notes allowed.
- Non-programmable scientific calculators are permitted.
- **Show all your work.**
- Remember to include units in all your calculations.
- Use an appropriate number of sig figs in your final answer.
- Marks will be deducted if units are not shown in your final answer.
- 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.

Warning:

Cellular phones, unauthorized electronic devices or course notes are not allowed during this exam. Phones and devices must be turned off and put away in your bag. Do not keep them in your possession, such as in your pockets. If caught with such a device or document, academic fraud allegations will be filed which may result in your obtaining a **0** (zero) for the midterm.

Q1: _____/8 Q2: _____/15 Q3: _____/3 Q3: _____/14

Total = _____/40

Question 1

- a) What is the compression factor (z) of an ideal gas? (1 mark)

$$z = \frac{V_m}{V_m^0} = 1$$

- b) What do you think will happen to the compression factor for a real gas that is subjected to high pressures at standard temperature? Briefly explain your reasoning. (2 marks)

V_m WILL BECOME LARGER THAN V_m^0
BECAUSE AT HIGH PRESSURES THE GAS
MOLECULES WILL START TO REPEL
EACH OTHER. $\therefore z > 1$

- c) If a real gas with attractive interactions is allowed to undergo a free isothermal expansion (i.e. against no external pressure), will q be greater than, less than, or equal to zero? Briefly explain your reasoning. (2 marks)

$p_{\text{ext}} = 0 \therefore w = 0$ IF GAS IS IDEAL $q = 0$
BUT IF ATTRACTIVE INTERACTIONS THEN ENERGY IS
NEEDED TO BREAK INTERACTIONS. SINCE
THIS IS ISOTHERMAL EXPANSION ENERGY MUST
COME FROM SURROUNDINGS $\therefore q > 0$

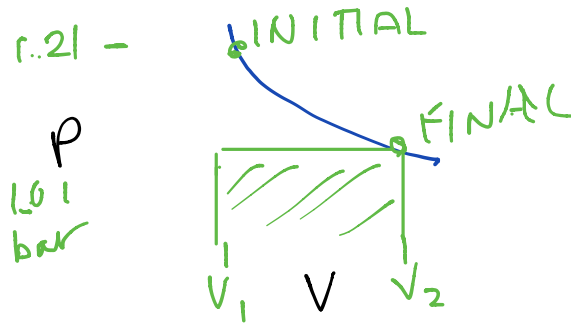
- d) Derive the equation for reversible isothermal work of a real gas that follows the modified version of the van der Waals equation shown below. (4 marks)

$$p = \frac{nRT}{V} - a\left(\frac{n}{V}\right)^2$$
$$w = -\int p_{\text{ext}} dV = -\int p dV$$
$$= -\int \left[\frac{nRT}{V} - a\left(\frac{n}{V}\right)^2 \right] dV$$
$$= -nRT \int_{V_1}^{V_2} \frac{dV}{V} - an^2 \int_{V_1}^{V_2} \frac{dV}{V^2}$$
$$= -nRT \ln\left(\frac{V_2}{V_1}\right) + an^2 \left(\frac{1}{V_2} - \frac{1}{V_1}\right)$$

Question 2

A weight is removed from a diathermic piston containing 0.126 mol of an ideal gas ($C_{V,m} = \frac{3}{2}R$) at 298.15 K, 1.21 bar, allowing the gas to rapidly expand until the final pressure of the gas is the same as the external pressure of 1.01 bar.

- a) Draw the work of this process on a pressure versus volume diagram. Be sure to label your axes, the initial and final state, and isotherm(s). (3 marks)



- b) What is ΔU for the gas? (1 mark)

$$\text{ISOTHERMAL} \therefore 0$$

- c) What is the work of this process? (3 marks)

$$\begin{aligned} W &= -p_{\text{ext}} \Delta V \\ &= -p_2 \left(\frac{nRT}{p_2} - \frac{nRT}{p_1} \right) \\ &= -nRT p_2 \left(\frac{1}{p_2} - \frac{1}{p_1} \right) \\ &= (0.126 \text{ mol}) (8.314 \frac{\text{J}}{\text{K} \cdot \text{mol}}) (298.15 \text{ K}) (1.01 \text{ bar}) \left(\frac{1}{1.01 \text{ bar}} - \frac{1}{1.21 \text{ bar}} \right) \\ &= -51.6 \text{ J} \end{aligned}$$

- d) What is the entropy change for the gas? (2 marks)

$$\begin{aligned} \Delta S &= nR \ln \left(\frac{V_2}{V_1} \right) \\ &= (0.126 \text{ mol}) (8.3145 \text{ K}^{-1} \text{ mol}^{-1}) \ln \left(\frac{1.21}{1.01} \right) \\ &= 0.189 \text{ J K}^{-1} \end{aligned}$$

- e) What would be the entropy change for the surroundings, assuming that the temperature of the surroundings is also 298.15K? (3 marks)

$$\begin{aligned}\Delta S_{\text{Surr}} &= -\frac{q_{\text{IRR. SYS}}}{T_{\text{Surr}}} \\ &= -\frac{(-W)}{T_{\text{Surr}}} = -\frac{(+51.6 \text{ J})}{298.15 \text{ K}} \\ &= -0.173 \text{ J K}^{-1}\end{aligned}$$

- f) What would be final temperature of this gas if the same amount of work was done was adiabatically? (3 marks)

$$\begin{aligned}W &= n C_{v,m} \Delta T = \Delta U \\ \Delta T &= \frac{W}{n C_{v,m}} = -\frac{51.6 \text{ J K}^{-1}}{(0.126 \text{ mol}) \left(\frac{5}{2}\right) (8.314 \frac{\text{J}}{\text{K mol}})} \\ &= -32.8 \text{ K} \\ T_2 &= 265. \text{ K}\end{aligned}$$

Question 3

If the heat of combustion of coal under standard conditions is 25 kJ/g, how many grams of coal would be required to obtain 450 kJ of work from a heat engine operating via a Carnot cycle between 5.0°C and 95.0°C? (3 marks)

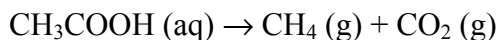
$$\begin{aligned}q_p &= 25 \frac{\text{kJ}}{\text{g}} & W &= 450 \text{ kJ} \\ & & T_h &= 95.0 = 368.15 \text{ K} \\ & & T_L &= 278.15 \text{ K} \\ \eta &= 1 - \frac{T_c}{T_h} = 1 - \frac{278.15 \text{ K}}{368.15 \text{ K}} = 0.244\end{aligned}$$

$$\begin{aligned}\eta &= \frac{W}{q_{\text{ABSORBED}}} & q &= \frac{W}{\eta} = \frac{450 \text{ kJ}}{0.244} \\ & & &= 1841 \text{ kJ}\end{aligned}$$

$$\begin{aligned}q &= m q_{\text{SPECIFIC}} \\ m &= \frac{1841 \text{ kJ}}{25 \text{ kJ/g}} = 74 \text{ g}\end{aligned}$$

Question 3

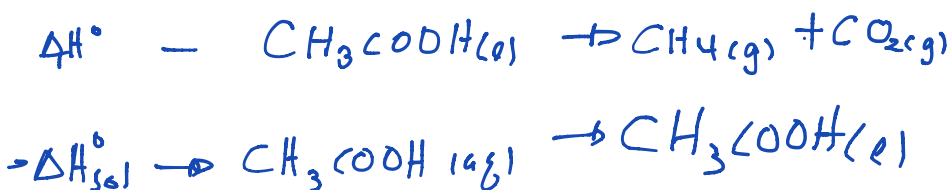
Acetotrophic bacteria can convert acetic acid into methane and carbon dioxide by the chemical reaction:



Answer the following questions about this reaction, using the data provided in the table when needed

- a) Calculate the standard molar enthalpy at 298.15 K for this reaction using the data provided. Be sure to pay attention to the phases. (3 marks)

Physical Property (at 298.15 K)	Value
$\Delta_f H_m^\circ(\text{CH}_3\text{COOH}(l))$	$-484.3 \text{ kJ mol}^{-1}$
$\Delta_f H_m^\circ(\text{CH}_4(g))$	$-74.6 \text{ kJ mol}^{-1}$
$\Delta_f H_m^\circ(\text{CO}_2(g))$	$-393.5 \text{ kJ mol}^{-1}$
$\Delta_{sol} H_m^\circ(\text{CH}_3\text{COOH})$	-1.5 kJ mol^{-1}
$C_{p,m}^\circ(\text{H}_2\text{O}(l))$	$75.291 \text{ J K}^{-1} \text{ mol}^{-1}$
$C_{p,m}^\circ(\text{CH}_4(g))$	$35.31 \text{ J K}^{-1} \text{ mol}^{-1}$
$C_{p,m}^\circ(\text{CO}_2(g))$	$37.11 \text{ J K}^{-1} \text{ mol}^{-1}$
$C_{p,m}^\circ(\text{CH}_3\text{COOH}(aq))$	$75.291 \text{ J K}^{-1} \text{ mol}^{-1}$



$$\Delta H = \Delta_f H^\circ(\text{CH}_4) + \Delta_f H^\circ(\text{CO}_2) - \Delta_f H^\circ(\text{CH}_3\text{COOH}(l)) - \Delta_{sol} H^\circ$$
$$= [-74.6 - 393.5 - (-484.3) - (-1.5)] \text{ kJ mol}^{-1}$$
$$= 17.7 \frac{\text{kJ}}{\text{mol}}$$

- b) Calculate the standard internal energy change for this reaction. (3 marks)

$$\Delta U^\circ = \Delta H_m - \Delta(pV)$$
$$= \Delta H - \Delta nRT$$
$$= 17.7 \frac{\text{kJ}}{\text{mol}} - (2-0) \left(8.314 \frac{\text{J}}{\text{K mol}} \right) (298.15 \text{ K}) \left(10^{-3} \frac{\text{kJ}}{\text{J}} \right)$$
$$= 12.7 \frac{\text{kJ}}{\text{mol}}$$

- c) Suppose bacteria was added to a 100 mL of a 0.500 M acetic acid solution in a thermally insulated open container, and the reaction allowed to proceed to completion under standard conditions. What is the total heat of this reaction? (2 marks)

$$n_{\text{ac}} = cV = \left(0.500 \frac{\text{mol}}{\text{L}}\right)(0.100 \text{L}) = 0.0500 \text{ mol}$$

$$q = n \Delta H^\circ$$

$$= (0.0500 \text{ mol})(17.7 \text{ kJ mol}^{-1})$$

$$= 885 \text{ J}$$

- d) What would be the heat of the reaction in c) if was run at 45.5°C? (3 marks)

$$\Delta H(318.65 \text{ K})$$

$$\leftarrow 318.65 \text{ K}$$

$$= \Delta_r H + n \Delta C_{p,m} \Delta T$$

$$= \Delta_r H + n [C_{p,m}(\text{C}_2\text{H}_4) + C_{p,m}(\text{CO}_2) - C_{p,m}(\text{CH}_3\text{COOH})] \Delta T$$

$$= 885 \text{ J} + (0.0500 \text{ mol}) [35.31 + 37.11 - 75.29] \frac{\text{J}}{\text{K mol}} (45.5 - 25.0) \text{ K}$$

$$= 882 \text{ J}$$

- e) The combustion reaction of acetic acid actually releases more energy than the reaction carried out by acetotrophic bacteria. Write the balanced chemical equation for the combustion of liquid acetic acid. Be sure to include phases in the chemical equation. (3 marks)



$$pV = nRT$$

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

$$p_A = x_A p_T$$

$$x_A = \frac{n_A}{n_{\text{Total}}}$$

$$z = \frac{V_m}{V_m^o}$$

$$\Delta U = w + q$$

$$dw = -p_{\text{ext}} dV$$

$$w = -p_{\text{ext}} \Delta V$$

$$w = -nRT \ln \left(\frac{V_2}{V_1} \right)$$

$$dU = q_V$$

$$C_p - C_V = nR$$

$$C_V = \left(\frac{\partial U}{\partial T} \right)_V$$

$$C_p = \left(\frac{\partial H}{\partial T} \right)_p$$

$$dH = q_p$$

$$q = It\Delta\phi$$

$$H = U + pV$$

$$\Delta H = \Delta U + \Delta n_g RT$$

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

$$p_1 V_1^\gamma = p_2 V_2^\gamma \quad \gamma = \frac{C_{p,m}}{C_{V,m}}$$

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

$$T_2 = T_1 \left(\frac{V_1}{V_2} \right)^{\frac{1}{c}} \quad c = \frac{C_{V,m}}{R}$$

$$V_1 T_1^c = V_2 T_2^c$$

$$w_{ad} = C_V \Delta T$$

$$\Delta_r H^\circ = \sum_{\text{Products}} \nu \Delta_f H^\circ - \sum_{\text{Reactants}} \nu \Delta_f H^\circ$$

$$\Delta_r H^\circ(T_2) = \Delta_r H^\circ(T_1) + \int_{T_1}^{T_2} \Delta_r C_p dT$$

$$\Delta_r H^\circ(T_2) = \Delta_r H^\circ(T_1) + \Delta_r C_p^\circ \Delta T$$

$$dS = \frac{dq_{\text{rev}}}{T}$$

$$\Delta S_{\text{surr}} = \frac{q_{\text{surr}}}{T_{\text{surr}}}$$

$$\Delta_r C_p = \sum_J \nu_J C_{p,m}(J)$$

$$\eta = 1 - \frac{T_c}{T_h}$$

$$dS \geq \frac{dq}{T}$$

$$\Delta S = nR \ln \frac{V_f}{V_i}$$

$$\Delta S_{\text{trs}}^\circ = \frac{\Delta H_{\text{trs}}^\circ}{T_{\text{trs}}}$$

$$S_m^\circ = S_m^\circ(298 \text{ K}) + \int_{T_1}^{T_2} C dT$$

$$S = k \ln W$$

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

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

$$\frac{dx^n}{dx} = nx^{n-1}$$

Constants

$$R = 8.314 \text{ J K}^{-1} \text{ mol}^{-1} = 0.08206 \text{ L atm mol}^{-1} \text{ K}^{-1} = 0.08314 \text{ L bar mol}^{-1} \text{ K}^{-1}$$

$$1 \text{ L} = 10^{-3} \text{ m}^3 \quad 1 \text{ kJ} = 1000 \text{ J} \quad 1 \text{ atm} = 101325 \text{ Pa} \quad 1 \text{ bar} = 10^5 \text{ Pa}$$

$$1 \text{ L atm} = 101.325 \text{ J} \quad 1 \text{ J} = 1 \text{ kg m}^2 \text{ s}^{-2} \quad 1 \text{ Pa} = 1 \text{ kg m}^{-1} \text{ s}^{-2}$$