

CHM2131A/CHM2132A Test 1: Friday October 1st, 2004

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. Marks will be deducted if units are not shown.

Constants and Data:

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

$$1 \text{ L} = 10^{-3} \text{ m}^3$$

$$1 \text{ atm} = 101325 \text{ Pa}$$

$$1 \text{ L atm} = 101.325 \text{ J}$$

$$\Delta_f H^\circ(\text{glucose(s)}) = -1274 \text{ kJ/mol}$$

$$\Delta_f H^\circ(\text{ethanol(l)}) = -277.7 \text{ kJ/mol}$$

$$\Delta_f H^\circ(\text{CO}_2(\text{g})) = -393.51 \text{ kJ/mol}$$

$$\Delta_{fus} H^\circ(\text{H}_2\text{O}) = 6.01 \text{ kJ/mol}$$

$$w = -\int p dV \quad \Delta U = w + q \quad H = U + pV \quad pV = nRT$$

$$p_1 V_1^\gamma = p_2 V_2^\gamma, \quad \gamma = \frac{C_p}{C_v} \quad C_{p,m} - C_{v,m} = R$$

$$\left(\frac{\partial U}{\partial T} \right)_V = C_V \quad \left(\frac{\partial H}{\partial T} \right)_P = C_P \quad \pi_T = \left(\frac{\partial U}{\partial V} \right)_T$$

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

Q1: _____/3 Q2: _____/10 Q3: _____/3 Q4: _____/16

Q5: _____/15 Q6: _____/3

Total = _____/50

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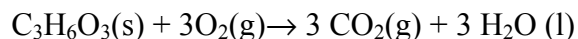
1. Indicate whether the following systems are open, closed or isolated (3 marks). (1 mark for each correct answer.)

a) The air inside a sealed bicycle tire.
closed

b) A perfectly insulated sealed cooler.
isolated

c) Prof. Goto's pet hamster Reddy.
open

2. a) Write the balanced chemical equation for the standard combustion reaction of lactic acid ($\text{CH}_3\text{CH}(\text{OH})\text{COOH}(\text{s})$). You must indicate the phases of compounds involved. (4 marks)



1 mark for phases and 1 mark for each correctly balanced product and O_2

b) Using the data on the first page calculate the *total* standard reaction enthalpy when 0.5 moles of glucose is consumed in the following reaction (5 marks):



Remember to state your final answer in a sentence.

$$\begin{aligned}\Delta_r H_m^\circ &= \sum_{\text{Products}} \nu \Delta_f H_m^\circ - \sum_{\text{Reactants}} \nu \Delta_f H_m^\circ \\ &= 2\Delta_f H_m^\circ(\text{ethanol}(\text{l})) + 2\Delta_f H_m^\circ(\text{CO}_2(\text{g})) - \Delta_f H_m^\circ(\text{glucose}(\text{s})) \\ &= 2(-277.7 \text{ kJ/mol}) + 2(-393.51 \text{ kJ/mol}) - (-1274 \text{ kJ/mol}) \\ &= -68.42 \text{ kJ/mol}\end{aligned}$$

(3 marks – formula must be written down accurately.)

Since $n=0.5$ moles;

$$\begin{aligned}\Delta_r H^\circ &= n \times \Delta_r H_m^\circ \\ &= (0.5 \text{ mol})(-68.42 \text{ kJ/mol}) \quad \text{2 marks} \\ &= -34.21 \text{ kJ}\end{aligned}$$

Therefore the total standard reaction enthalpy is -34 kJ for this reaction.

c) Is the above reaction exothermic or endothermic? (1 mark)

exothermic (since it gives off heat) (1 mark)

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3. Evaluate $\left(\frac{\partial p}{\partial T}\right)_{V,n}$ for the ideal gas equation. (3 marks)

Substitute $p = \frac{nRT}{V}$ into the partial derivative: (1 mark)

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

(1 mark for correct substitution and pulling out constants, 1 mark for correct answer)

4. 1.2 mol of an ideal gas is trapped in a piston at equilibrium with its surroundings at 0.5 atm and 298.15 K. The gas then undergoes an isothermal reversible expansion from a volume of 2.50 L to 10.0 L. The molar constant-volume heat capacity of this gas is $27.5 \text{ J K}^{-1} \text{ mol}^{-1}$.

a) What is the final pressure of the gas? State your final answer in a sentence. (2 marks)

There were 2 possible solutions to this question:

$$p_1 V_1 = p_2 V_2$$

$$p_2 = \frac{p_1 V_1}{V_2}$$

$$= \frac{(0.5 \text{ atm})(2.50 \text{ L})}{(10.0 \text{ L})}$$

$$= 0.1 \text{ atm}$$

or

$$p_2 = \frac{nRT_2}{V_2} = \frac{(1.2 \text{ mol})(8.314 \text{ J K}^{-1} \text{ mol}^{-1})(298.15 \text{ K})}{(10.0 \text{ L})(10^{-3} \text{ m}^3 \text{ L}^{-1})}$$

$$= 297 \text{ kPa or 3 atm}$$

Therefore the final pressure was 0.1 atm (or 3 atm).

(1 mark for correct equation, 1 mark for correct answer)

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b) What is the total work and the total heat of this process? State your final answers in a sentence. (5 marks)

Since this is a reversible isothermal process we can substitute the ideal gas equation for pressure

$$p = \frac{nRT}{V} \text{ into } w = -\int p dV$$

$$w = -\int \frac{nRT}{V} dV$$

$$= -nRT \int_{V_1}^{V_2} \frac{dV}{V}$$

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

$$= (-1.2 \text{ mol})(8.314 \text{ J K}^{-1} \text{ mol}^{-1})(298.15 \text{ K}) \ln\left(\frac{10.0 \text{ L}}{2.50 \text{ L}}\right)$$

$$= -4.1 \text{ kJ}$$

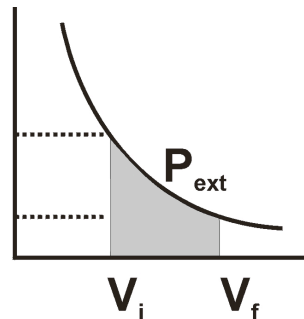
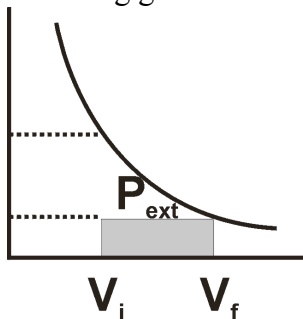
(1 mark for correct equation, 1 mark for correct substitution, 1 mark for correct answer)

Since $\Delta U = 0$, therefore $q = -w$ (1 mark) = 4.1 kJ (1 mark).

Therefore the total work of the process is -4.1 kJ and the total heat of the process is 4.1 kJ.

c) Is it possible for this gas to do more work without giving the system any more energy? Briefly explain your answer using p - V diagrams. (4 marks)

The area under a p - V plot of an expansion process gives the amount of work associated with this gas expansion (1 mark). Shown below are p - V graphs for expansions done either irreversibly (left) or reversibly (right) (2 marks – 1 for each correctly drawn graph). Neither process shown requires more energy since neither process would increase the temperature of the gas. (Paths that increase the gas temperature would be above the isotherm.) (1 mark) Since the area under the curve is largest for the reversible process therefore the work for the reversible process is the maximum that this gas can do without being given more energy.



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d) What would be the final pressure of this gas if this same expansion were **not** carried out *isothermally*, but instead *adiabatically*? Please put your final answer in the form of a sentence. (5 marks)

Since this is a reversible adiabatic process, and we know p_2 , V_2 , p_1 and $C_{v,m}$ we can use:

$$p_1 V_1^\gamma = p_2 V_2^\gamma \quad (1 \text{ mark})$$

$$\text{where } \gamma = \frac{C_{p,m}}{C_{v,m}} \quad (1 \text{ mark})$$

Since $C_{p,m} - C_{v,m} = R$

$$\gamma = \frac{R + C_{v,m}}{C_{v,m}} \quad (1 \text{ mark})$$

$$p_2 = p_1 \left(\frac{V_1}{V_2} \right)^{\frac{R + C_{v,m}}{C_{v,m}}}$$
$$= (0.5 \text{ atm}) \left(\frac{2.5 \text{ L}}{10.0 \text{ L}} \right)^{\frac{8.314 \text{ J K}^{-1} \text{ mol}^{-1} + 27.5 \text{ J K}^{-1} \text{ mol}^{-1}}{27.5 \text{ J K}^{-1} \text{ mol}^{-1}}} \quad (1 \text{ mark for correct substitution, 1 for correct answer})$$

$$= 0.08 \text{ atm}$$

Therefore the final pressure would be 0.08 atm.

5. For the following processes, indicate whether ΔT , ΔU , ΔH , q , and w is greater than, less than or equal to zero. (15 marks) (1 mark for each correct answer, no justification required in answer.)

a) An ideal gas isothermally and irreversibly expands into a vacuum.

$$\Delta T = 0 \quad (\text{since isothermal})$$

$$\Delta U = 0 \quad (\text{isothermal } p\text{-}V \text{ process involving an ideal gas always has no change in internal energy})$$

$$\Delta H = 0 \quad (\text{isothermal } p\text{-}V \text{ process involving an ideal gas always has no change in enthalpy})$$

$$w = 0 \quad (\text{irreversible expansion, } p_{\text{ext}} = 0)$$

$$q = 0 \quad (\text{since } \Delta U = 0, q = -w)$$

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b) An ice cube melts in a cup. (The density of liquid water is greater than that of solid ice.)

$\Delta T = 0$ (Since the temperature of ice and water in equilibrium is zero.)

$\Delta H > 0$ (Heat must be supplied to melt ice; also given as data on page one.)

$q > 0$ ($q = q_p = \Delta H$)

$\Delta U > 0$ (Heat must be supplied to melt ice under constant volume conditions.)

$w > 0$ (H_2O going from less compact state (ice) to more compact state (water) – therefore it is shrinking, or $\Delta V < 0$. Since $w = -\int p dV$, work must be positive.)

c) A balloon filled with an ideal gas undergoes a reversible expansion against a constant external pressure.

$\Delta T > 0$ (since $\frac{V_1}{V_2} = \frac{T_1}{T_2}$ and $\frac{V_1}{V_2} < 1$ therefore $\frac{T_1}{T_2} < 1$ or $T_1 < T_2$)

$\Delta H > 0$ (Since $\Delta H = C_p \Delta T$)

$q > 0$ ($q = q_p = \Delta H$)

$\Delta U > 0$ (Since $\Delta U = C_v \Delta T$)

$w < 0$ (Since $\Delta V > 0$)

6. For a real gas with repulsive forces dominant is the internal pressure of a real gas (π_T) greater than or less than zero? Justify your answer using no more than two sentences. (3 marks)

For a gas with repulsive forces dominant the gas molecules would be in a high energy state at low volumes where the molecules are forced to be closer together and a lower energy state at higher volumes as the molecules are allowed to move apart. (1 mark) Therefore the internal energy would decrease with increasing (or increase with decreasing volume) (1 mark) which according to

the equation for π_T $\left(\pi_T = \left(\frac{\partial U}{\partial V} \right)_T \right)$ would lead to an internal pressure of less than zero (1 mark).