The Richard Stockton College of New Jersey
Chemistry Program, School of Natural Sciences and Mathematics
PO Box 195, Pomoma, NJ

CHEM 3410: Physical Chemistry I — Fall 2008

Exam 1 — Model Solutions

October 3, 2008

12:45–2 PM

Name: Key

Read all of the following information before starting the exam:

- This is a closed book exam. You are permitted an aid sheet consisting of two sides of a 8.5" x 11" piece of paper. **Your aid sheet must be turned in with your exam.**
- Show all work, clearly and in order, if you want to get full credit. I reserve the right to take off points if I cannot see how you arrived at your answer (even if your final answer is correct).
- Please keep your written answers brief; be clear and to the point. I will take points off for rambling and for incorrect or irrelevant statements.
- Justify your answers. Clearly state any assumptions you make.
- Circle or otherwise indicate your final answers.
- You have 75 minutes to complete the exam. There are a total of 70 points on the exam, so budget your time accordingly.
- For problems involving calculations, set up your calculations first and then do the computation if time permits.
- Be sure to read all the questions first. You do not have to complete the problems in any particular order.
- Good luck!

Use of wireless communication devices at any time during the exam is strictly prohibited.

Question	Score	Total
1		14
2		16
3		20
4		20
Total		70

1. (*14* points) For the following complete processes, predict whether q, w, ΔU, and ΔS for the system will be positive (+), negative (−), or equal to zero (0). Enter your answers in the tables and explain **briefly** in the space provided, no calculations necessary.

(a) A sample of an ideal gas is carried through a complete Carnot cycle (isothermal expansion, adiabatic expansion, isothermal compression, and adiabatic compression — all reversible). (**7**)

q	w	ΔU	ΔS
+	−	0	0

For any cyclic process the change in a state function will be zero, so ΔU and ΔS are both equal to zero. In the Carnot cycle, there is a net output of work (the system does work) meaning $w < 0$ and since $\Delta U = 0$, $q > 0$.

(b) An ideal gas expands adiabatically and reversibly. (**7**)

q	w	ΔU	ΔS
0	−	−	0

The process is done adiabatically, so there is no heat flow and $q = 0$. Since the process is also reversible, $q_{rev} = 0$ and $\Delta S = 0$. Finally, the gas is expanding, meaning work is being done by the gas and $w < 0$ and thus $\Delta U < 0$.

2. (*16* points) While running a marathon, it is not unusual for a runner to consume 4 L (4 kg) of H_2O and to lose about 4 kg of body mass. For simplicity, pretend that all of the loss of body mass is due to loss of H_2O (g, $T = 37°C$ $P = 1$ atm) by evaporation.

Using the data below, compute ΔH_{system} and ΔS_{system} for the conversion of 8.0 kg of H_2O from liquid to vapor at T = 37°C. You may assume that the heat capacities are independent of temperature.

$\Delta H_{vap}(100°C) = 41$ kJ/mol

$C_p(H_2O, g) = 34$ J/mol-K

$C_p(H_2O, l) = 75$ J/mol-K

Molecular weight (molar mass) of H_2O = 18 g/mol = 0.018 kg/mol

We need to figure out the enthalpy of vaporization at 310 K (37°C). We know the enthalpy of vaporization at 373 K and the heat capacities of the liquid and gas, so we need to employ a Hess's loop to figure out the enthalpy at 310 K.

$$\Delta H(310\ K) = \int_{310}^{373} nC_p^l dT + n\Delta H_{vap}(373\ K) + \int_{373}^{310} nC_p^g dT$$

8.0 kg of water is equivalent to 444.4 moles of water. Since the heat capacities are independent of temperature:

$$\Delta H(310\ K) = nC_p^l \Delta T\Big|_{310}^{373} + n\Delta H_{vap}(373\ K) + nC_p^g \Delta T\Big|_{373}^{310}$$

$$\Delta H(310\,K) = 444.4\,mol\,[75\ J/molK(373 - 310) + 41000\ J/mol + 34\ J/molK(310 - 373)]$$

$$\boxed{\Delta H(310\ K) = 19368\ kJ = 19.37\ MJ}$$

To find the entropy change we employ a similar strategy:

$$\Delta S(310\ K) = \int_{310}^{373} \frac{nC_p^l dT}{T} + \frac{n\Delta H_{vap}(373\ K)}{T_{vap}} + \int_{373}^{310} \frac{nC_p^g dT}{T}$$

$$\Delta S(310\ K) = 444.4\left[75\ J/molK \ln\frac{373}{310} + \frac{41000\ J/mol}{373\ K} + 34\ J/molK \ln\frac{310}{373}\right]$$

$$\boxed{\Delta S(310\ K) = 52.2\ kJ/K}$$

3. (*20* points) Consider 1 mol of a monatomic ideal gas initially at $P_1 = 1$ atm, $T_1 = 300$ K, $V_1 = 25$ L. The heat capacity at constant volume for this gas is $C_v = \frac{3}{2}R$. For the following processes, all of which end at final volume $V_2 = 50$ L, give the results for w, q, ΔU, ΔH, and ΔS for the system. Show your work below and enter your results in the table. You may use any system of units you like, but be consistent throughout your answer.

It is important to note that part (a) and (b) end up in different states, so values of state functions for the processes are going to be different for each part. Also, you might have noticed that the initial temperature, pressure, and volume are not physical since they do not conform to the ideal gas law.

(a) Reversible, constant pressure heating until volume V_2 is reached. (***10***)

For a constant pressure heating we can find the work:

$$w = \int -PdV = -P\int dV = -P\Delta V = -1\ atm(50 - 25\ L) - 25\ Latm = -2532\ J$$

The volume doubles, so the temperature must also double giving us a final temperature of 600 K. This is a constant pressure heating so:

$$q_p = \Delta H = \int C_p dT = \frac{5}{2}R\Delta T = \frac{5}{2}R(600 - 300\ K) = 6236\ J$$

$$\Delta U = q + w = -2532 + 6236 = 3704\ J$$

Finally, we can find ΔS:

$$\Delta S = \int_{300}^{600} \frac{C_p dT}{T} = \frac{5}{2}R\ln\frac{600}{300} = 14.4\ J/K$$

(b) Reversible isothermal expansion to volume V_2. (***10***)

Since this is an isothermal process involving an ideal gas, we can immediately write down that $\Delta U = \Delta H = 0$. This leaves us with q = -w.

$$w = \int_{V_1}^{V_2} -PdV$$

But pressure is NOT constant, so we need to write P in terms of V using the ideal gas law:

$$w = \int_{V_1}^{V_2} -\frac{nRT}{V}dV = -nRT\ln\frac{V_2}{V_1} = -R(300\ K)\ln\frac{50}{25} = -1729\ J$$

$$\Delta S = \frac{q}{T} = \frac{1729\ J}{300\ K} = 5.76\ J/K \quad \text{(since it is isothermal)}$$

	w	q	ΔU	ΔH	ΔS
Part (a)	−2532 J	6236 J	3704	6236	14.4 J/K
Part (b)	−1729 J	+1729 J	0	0	5.76 J/K

4. (*20* points) Please identify each of the following statements as true or false. Give a brief justification for each answer.

   (a) The entropy of a *universe* must always increase for a spontaneous process. (***5***)

   TRUE. This is a result of the second law. For a process to occur spontaneously, the entropy of the universe must increase.

   (b) For a reversible, cyclic process $\Delta U > 0$. (***5***)

   FALSE. For any cyclic process the change in a state function is EQUAL to zero. This is because a state function only depends on the initial and final states. If the initial and final states are the same, as they are in a cylce, the change in a state function is zero.

   (c) In an reversible, isothermal expansion of an ideal gas, the internal energy always decreases. (***5***)

   FALSE. For any isothermal process involving an ideal gas, the internal energy change is equal to zero.

   (d) A piece of iron at 400 K contains more heat than a piece of iron at 300 K. (***5***)

   FALSE. Heat is not a substance. An object cannot contain more heat than another object.

Potentially useful information

R = 0.0821 L·atm/mol·K = 8.314 J/mol·K

$PV = nRT$ for an ideal gas

The Periodic Table of the Elements

1 **H** Hydrogen 1.00794																	2 **He** Helium 4.003
3 **Li** Lithium 6.941	4 **Be** Beryllium 9.012182											5 **B** Boron 10.811	6 **C** Carbon 12.0107	7 **N** Nitrogen 14.00674	8 **O** Oxygen 15.9994	9 **F** Fluorine 18.9984032	10 **Ne** Neon 20.1797
11 **Na** Sodium 22.989770	12 **Mg** Magnesium 24.3050											13 **Al** Aluminum 26.981538	14 **Si** Silicon 28.0855	15 **P** Phosphorus 30.973761	16 **S** Sulfur 32.066	17 **Cl** Chlorine 35.4527	18 **Ar** Argon 39.948
19 **K** Potassium 39.0983	20 **Ca** Calcium 40.078	21 **Sc** Scandium 44.955910	22 **Ti** Titanium 47.867	23 **V** Vanadium 50.9415	24 **Cr** Chromium 51.9961	25 **Mn** Manganese 54.938049	26 **Fe** Iron 55.845	27 **Co** Cobalt 58.933200	28 **Ni** Nickel 58.6934	29 **Cu** Copper 63.546	30 **Zn** Zinc 65.39	31 **Ga** Gallium 69.723	32 **Ge** Germanium 72.61	33 **As** Arsenic 74.92160	34 **Se** Selenium 78.96	35 **Br** Bromine 79.904	36 **Kr** Krypton 83.80
37 **Rb** Rubidium 85.4678	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.90585	40 **Zr** Zirconium 91.224	41 **Nb** Niobium 92.90638	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium (98)	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.90550	46 **Pd** Palladium 106.42	47 **Ag** Silver 107.8682	48 **Cd** Cadmium 112.411	49 **In** Indium 114.818	50 **Sn** Tin 118.710	51 **Sb** Antimony 121.760	52 **Te** Tellurium 127.60	53 **I** Iodine 126.90447	54 **Xe** Xenon 131.29
55 **Cs** Cesium 132.90545	56 **Ba** Barium 137.327	57 **La** Lanthanum 138.9055	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.9479	74 **W** Tungsten 183.84	75 **Re** Rhenium 186.207	76 **Os** Osmium 190.23	77 **Ir** Iridium 192.217	78 **Pt** Platinum 195.078	79 **Au** Gold 196.96655	80 **Hg** Mercury 200.59	81 **Tl** Thallium 204.3833	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.98038	84 **Po** Polonium (209)	85 **At** Astatine (210)	86 **Rn** Radon (222)
87 **Fr** Francium (223)	88 **Ra** Radium (226)	89 **Ac** Actinium (227)	104 **Rf** Rutherfordium (261)	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (263)	107 **Bh** Bohrium (262)	108 **Hs** Hassium (265)	109 **Mt** Meitnerium (266)	110 (269)	111 (272)	112 (277)	113	114				

58 **Ce** Cerium 140.116	59 **Pr** Praseodymium 140.90765	60 **Nd** Neodymium 144.24	61 **Pm** Promethium (145)	62 **Sm** Samarium 150.36	63 **Eu** Europium 151.964	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.92534	66 **Dy** Dysprosium 162.50	67 **Ho** Holmium 164.93032	68 **Er** Erbium 167.26	69 **Tm** Thulium 168.93421	70 **Yb** Ytterbium 173.04	71 **Lu** Lutetium 174.967
90 **Th** Thorium 232.0381	91 **Pa** Protactinium 231.03588	92 **U** Uranium 238.0289	93 **Np** Neptunium (237)	94 **Pu** Plutonium (244)	95 **Am** Americium (243)	96 **Cm** Curium (247)	97 **Bk** Berkelium (247)	98 **Cf** Californium (251)	99 **Es** Einsteinium (252)	100 **Fm** Fermium (257)	101 **Md** Mendelevium (258)	102 **No** Nobelium (259)	103 **Lr** Lawrencium (262)