CH353 – Physical Chemistry I
Spring 2015, Unique 51170

Exam 1 – February 10, 2015

Name: Key

Always assume ideal gas unless directed otherwise.

You may use any material that does not have a heartbeat and does not connect to the internet or cellular network. Calculators may be used for computing arithmetic only.

Honor Code:

"The core values of the University of Texas at Austin are learning, discovery, freedom, leadership, individual opportunity, and responsibility. Each member of the University is expected to uphold these values through integrity, honesty, trust, fairness, and respect toward peers and community."

I certify that the work on this exam is entirely my own.

Signature Date

Periodic Table of the Elements

Chemistry Reference Sheet

California Standards Test

11
Na
Sodium
22.99

1 H Hydrogen 1.01																	2 He Helium 4.00
3 Li Lithium 6.94	4 Be Beryllium 9.01											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 16.00	9 F Fluorine 19.00	10 Ne Neon 20.18
11 Na Sodium 22.99	12 Mg Magnesium 24.31											13 Al Aluminum 26.98	14 Si Silicon 28.09	15 P Phosphorus 30.97	16 S Sulfur 32.07	17 Cl Chlorine 35.45	18 Ar Argon 39.95
19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.87	23 V Vanadium 50.94	24 Cr Chromium 52.00	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.39	31 Ga Gallium 69.72	32 Ge Germanium 72.61	33 As Arsenic 74.92	34 Se Selenium 78.96	35 Br Bromine 79.90	36 Kr Krypton 83.80
37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niobium 92.91	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.60	53 I Iodine 126.90	54 Xe Xenon 131.29
55 Cs Cesium 132.91	56 Ba Barium 137.33	57 La Lanthanum 138.91	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98	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 (266)	107 Bh Bohrium (264)	108 Hs Hassium (269)	109 Mt Meitnerium (268)									

58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.97
90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	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)

1. (20 points) Determine if the following statements are true or false.

a. True [✓ False] For a monatomic van der Waals gas, $a = 3/2R$.

b. True [✓ False] Only molecules that contain a permanent dipole moment have van der Waals intermolecular forces.

c. [✓ True] False When a system does work on its surroundings, $w < 0$

d. [✓ True] False Gases at sufficiently low pressure do not display van der Waals intermolecular forces.

e. True [✓ False] In an adiabatic process, $\Delta T=0$ always.

f. True [✓ False] The total pressure of a system composed of molecules A, B, and C will always be larger than a system composed only of molecules A and B.

2. (15 points) A vessel containing 1 mol of an ideal gas expands isothermally and reversibly from 10.0 L to 40.0 L at 600 K. An identical vessel containing 1 mol of a different gas which obeys the following state function:

$$V = \frac{nRT}{P} + nd, \quad d = 3.2 \text{ L/mol}$$

undergoes the same process.

a. Is the second gas behaving ideally, or is it dominated by attractive or repulsive forces under these conditions?

There are many ways to solve this, but by inspection, since the +nd factor increases volume, this gas has repulsive forces. See next page for numbers.

b. Determine the work done by each gas undergoing this expansion.

Reversible: $w(\text{ideal}) = -nRT\ln\left(\frac{V_f}{V_i}\right) = -6912\text{ J}$

$w(\text{non ideal}) = -nRT\ln\left(\frac{V_f - nd}{V_i - nd}\right) = -8419\text{ J}$

c. If your answer for work in part b) was different for each gas, explain why in clear, comprehensible English.

The nonideal gas is at higher pressure than the ideal gas. It is thus able to do more work because of the presence of repulsive forces.

2a. long version

$Z = \frac{PV_m}{RT}$ need P_f of nonideal gas

$$P_f = \frac{nRT}{V-nd} = \frac{(1.0\,mol)(0.082\,\frac{L\,atm}{mol\,K})(600\,K)}{40.0\,L - (1.0\,mol)(3.2\,L/mol)}$$

$P_f = 1.34\,atm$

$$Z = \frac{PV_m}{RT} = \frac{(1.34\,atm)(40.0\,L)}{(0.082\,L\,atm/mol\,K)(600\,K)}$$

$\boxed{Z = 1.1}$ $Z > 1$, so repulsive forces dominate (slightly)

You can also just calculate P_f under ideal + non ideal conditions and compare:

P_f (ideal) = 1.23 atm

P_f (nonideal) = 1.34 atm

P_f (nonideal) > P_f (ideal) => repulsive forces dominate.

3. (25 points) It is recommended that a healthy human adult eat approximately 2000 food calories per day to maintain a normal basal metabolic rate: the amount of energy used at rest in a temperate environment to run all normal body functions. Exercise burns additional energy on top of normal basal metabolic functions. In this problem, assume that the human body is 100% water and has a heat capacity approximately that of liquid water, 75.3 J K^{-1} mol^{-1} You may also assume a body mass of 80 kg. Note: 1 food calorie = 1 kcal = 4180 [illegible]. J

a. If the body had no cooling mechanism, how much would its temperature increase over the course of a day?

heat from 2000 food calories $= 2000 \times 10^3 \text{cal} \left(\frac{4.18 \text{J}}{\text{cal}}\right) = 8.36 \times 10^6 \text{J} = q_P$ (P = 1 atm, constant)

assume 80 kg of H_2O: $FW(H_2O) = 18 \text{g/mol} = 0.018 \text{kg/mol}$

$n = \frac{80 \text{kg}}{0.018 \text{kg/mol}} \approx 4444 \text{mols } H_2O$

$q_p = nC_{p,m}\Delta T$, $\Delta T = \frac{q_p}{n(C_{p,m})}$, $= \frac{(8.36 \times 10^6 \text{J})}{(4444 \text{mols})(75.3 \text{J/Kmol})} = \boxed{25 \text{K}}$!!!

b. The body's primary cooling mechanism is sweating, which uses heat from the skin to evaporate water (an endothermic process). Sweating can remove 40.7 kJ/mol of heat from the human body. How much water is lost to sweating (evaporation) over the course of a day to maintain a normal body temperature of 37°C?

$q_p = nC_{p,m}\Delta T = 40.7 \text{kJ/mol}$

$n = \frac{q_p}{C_{p,m}\Delta T} = \frac{(40.7 \times 10^3 \text{J/mol})}{(75.3 \text{J/Kmol})(25 \text{K})} = 22 \text{mols}$

$m = (FW)n = (18 \text{g/mol})(22 \text{mols}) \approx \underline{396 \text{g}}$

c. Swimming is a strenuous activity that can burn up to 800 food calories per hour. The swimmer Michael Phelps reportedly trained 8 hrs a day leading up to the 2008 summer Olympics, burning an additional 6400 food calories on top of his basal metabolic rate. During that same time, he reportedly ate 12,000 food calories a day Where did the additional energy go?

Swimming usually occurs in a pool that is significantly below the temperature of the body. The swimmer is therefore spending energy keeping the body temperature at 37°C.

4. (20 points) 4 g of phosphorous pentachloride, $PCl_5(s)$, are placed in a 5.0 L container with rigid walls holding 1 atm of atmospheric air. A thermostat keeps the temperature of the container at room temperature. Under these conditions, $PCl_5(s)$ decomposes to $PCl_3(g)$ and $Cl_2(g)$:

$$PCl_5(s) \rightarrow PCl_3(g) + Cl_2(g)$$

Remember that atmospheric air is approximately 20% $O_2(g)$ and 80% $N_2(g)$. You may assume that atmospheric pressure is 1 atm.

a. What are the signs of ΔP, ΔV, ΔT, ΔU, and ΔH of the system? It would be helpful to define exactly what the system is in this example.

$\Delta P > 0$ $\quad$ $\Delta T = 0$

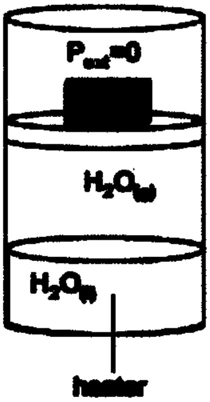
$\Delta V = 0$ $\quad$ $\Delta U = 0$

$\Delta H = 0$

b. 4 g of $PCl_5(s)$ decomposes to half its original mass. What is the partial pressure of $O_2(g)$ once that occurs?

$O_2(g)$ doesnot take place in the rxn $P(O_2) = 0.2$ atm before and after the decomposition.

5. (20 points) A simple heat engine drawn below consists of an adiabatic container of volume V and pressure P that holds a reservoir of $H_2O(l)$ of volume V_l in equilibrium with $H_2O_{(g)}$. The top of the liquid chamber is capped with an adiabatic, movable barrier that separates the liquid reservoir from a vacuum ($P_{ext} = 0$) and holds a weight of mass m. When the engine is cold, the barrier rests directly on top of the liquid. As heat is added to the liquid reservoir the water evaporates, and the water vapor lifts the barrier (shown in the figure). Derive an expression for the work achieved by this engine.



$w = -P\Delta V \quad \Delta V = V_f - V_i = (\cancel{V_l} + V_g) - \cancel{V_l} = V_g$

$V_g = \frac{nRT}{P}$

$w = -\cancel{P}\left(\frac{nRT}{\cancel{P}}\right) = -nRT$