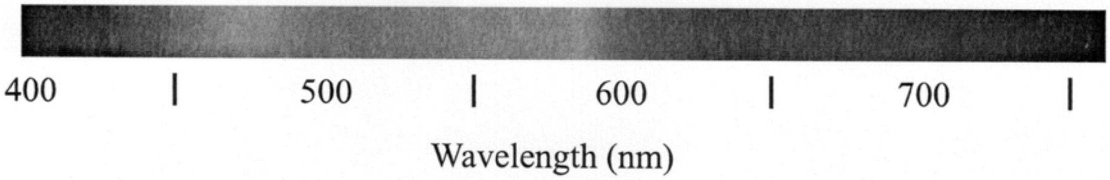
Chemistry 4A F14 | Midterm Exam 3 | November 19, 2014

Profs Head-Gordon & Whaley | **B** | Closed book, 50 minutes

Student name: KEY Student ID#: ____________

GSI name: ____________ Lab section or Day/Time: ____________

Potentially Useful Information



$$E_{\text{photon}} = h\nu \qquad p = mv \qquad \lambda\nu = c$$

$$E_{\text{kinetic}} = \frac{mv^2}{2} = \frac{p^2}{2m} \qquad E_{\text{kinetic}} = h\nu - \Phi \qquad \lambda_{\text{deBroglie}} = \frac{h}{p}$$

$$\binom{n}{k} = \frac{n!}{k!(n-k)!} \qquad \frac{1}{2}m\upsilon_{RMS} = \frac{3RT}{2} \qquad \varepsilon = \frac{T_h - T_l}{T_h}$$

$$\Delta H^\circ = \sum_{i=1}^{prod} n_i \Delta H_i^\circ - \sum_{j=1}^{react} n_j \Delta H_j^\circ \qquad \Delta S = nR\ln\left(\frac{V_f}{V_i}\right) \qquad \Delta G = \Delta H - T\Delta S$$

$c = 2.99792 \times 10^8$ m s^{-1}
$h = 6.62608 \times 10^{-34}$ J s
$m_p = 1.007$ amu $= 1.6726 \times 10^{-27}$ kg
1 nm = 1×10^{-9} m
R = 0.08206 L atm mol^{-1} K^{-1}

$N_A = 6.02212 \times 10^{23}$ mol^{-1}
$e = 1.602 \times 10^{-19}$ C
1 eV = 96.485 kJ/mol
1 Å = 1×10^{-10} m
R = 8.3145 J mol^{-1} K^{-1}

	Bond Enthalpy (kJ mol^{-1})
C-H	413
C-C	348
C=O	728
H-H	436
O-H	463
O=O	498
N≡N	940

m_e = 9.1(

MC: _______ / 24 #1: _______ / 15 #2: _______ / 15

#3: _______ /15

Total: ______ 71

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Multiple Choice Questions **Circle one answer** for each question (3 points each, 30 total)

1) The number of microstates for 5 distinguishable particles arranged in a container with two halves is:

a. 5 b. 10 c. 25 d. 32

2) What type of infrared absorption do you expect the N2 molecule to have?

a. positive b. weak c. negative d. strong

3) A car engine has an operating temperature of about 150C. If the surroundings are at 15C, what is the maximum efficiency that the engine could achieve?

a. 0.31 b. 0.44 c. 0.62 d. 0.98

4) Which is the best estimate of $\Delta H_f^{(0)}$ of nitrogen atoms? (all in kJ/mol)

a. -940 b. -470 c. 0 d. 940

5) A complex can be formed between Ar and CH4. What is the main intermolecular force that is responsible for the existence of this complex?

a. dipole-dipole b. electrostatic c. polarization d. dispersion

B

6) Which of the following molecules would be expected to have the highest boiling point?

a. CH_3OH b. CH_4 c. CH_3CH_3 d. CH_3F

7) Which of the following pressures (in atm) is the best estimate for the triple point of water?

a. 0.006 b. 0.6 c. 6 d. 600

8) Which of the following salts, per unit mass, might be expected to provide the largest freezing point depression (and thus, ignoring other effects) would be most effective on roads?

a. NaCl b. CaCl2 c. NaI d. NaF

B

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Short Answer Question #1 [15 points]
The discoverer of Charles' Law, Jacques Charles, was also very preoccupied with exploring balloon flight, and participated in the first flight using a hydrogen-filled balloon (in 1783!). For that flight, the hydrogen was produced by the reaction of sulfuric acid, H_2SO_4, on iron filings (55.8 g mol^{-1}), yielding iron (II) sulfate as well.

(a) (6 points) What mass of iron filings would be required to fill a balloon of radius 4m with hydrogen gas at 25.0°C and 1.00 atm pressure?

$H_2SO_4 + Fe \longrightarrow FeSO_4 + H_2$ +2 pts

$\frac{4}{3}\pi r^3 = V$ +1 pt

$\frac{256}{3}\pi\, m^3 = \frac{256,000}{3}\pi L = 268,083 L$

$55.8 \cdot \frac{268,083}{298 \cdot 0.08206} = m.\, Fe$ } +2 pts

611,723 g +1 pt

(b) (5 points) Suppose that as the intrepid ballooners and their balloon rose, the outside pressure dropped to 0.9 atm, and the temperature fell to a chilly -16.0°C. How would the volume of the balloon change (you may assume that the balloon material is perfectly flexible)?

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ +2 pts

$\frac{1 \cdot 268,083 \cdot 257}{298 \cdot .9} = 256,888 L$ +2 pts +1 pt

(c) (4 points) Given that the average energy per molecule in the kinetic theory is $3k_BT/2$, predict the ratio of the root mean square speeds of the molecules at -16°C versus 25°C.

$\frac{V_{25°C}}{V_{16°C}} = \sqrt{\frac{298}{257}} = 1.077$

+2 pts +1 pt +1 pt

B

KEY

Short Answer Question #2 [15 points]

(a) (6 points) Use average bond enthalpies to estimate the enthalpy of combustion for methane, CH4, the main component of natural gas (which is the main fuel coming from the nationwide fracking boom).

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ 2 pt

$-(4 \cdot 463 + 2 \cdot 728 - 2 \cdot 498 - 4 \cdot 413)$ kJ/mol 2 pt bonds formed − broken (signs)

H_2O 1852, CO_2 1456, O_2 996, CH_4 1652

3408 2648

= −660 kJ/mol

1 pt right numbers

1 pt sign final

1 pt magnitude final answer

(b) (6 points) Before methane can be burned, it must be heated to its ignition temperature of 600C. How much heat (in kJ mol^{-1}) is required to bring 0.5L of methane from STP to 600C at constant pressure (treat methane as an ideal gas in determining the c_p).

3 pt for $c_p = \frac{5}{2}R$, 4R, or 13R

$= \frac{7}{2}R$ give 2 pts

$c_p = \frac{5}{2}RT$ give 2 pts

2 pt $q = nc_p\Delta T$ (setting up)

$c_p = 13.5R$ give 2 pts

1 pt for q or $\frac{q}{n}$

	STP=25°C		STP=0°C	
c_p	q	q/n		
5/2R	0.239 kJ or 0.267	11.951 kJ/mol	0.2494 kJ	12.47 kJ/mol
4R	0.382 kJ	19.122 kJ/mol	0.3990 kJ	19.95 kJ/mol
13R	1.2429 kJ	62.147 kJ/mol	~~1.297 kJ~~ 1.4	64.85 kJ/mol

(c) (3 points) Discuss why a natural gas furnace would be expected to be more or less efficient (i.e. produce more or less heat per mole of methane burned) depending on whether the water vapor produced as a product is vented directly or condensed within the furnace.

3 pt − must include reason + specifically state which is more efficient

Condensing vapor being more efficient since condensation is exothermic

A

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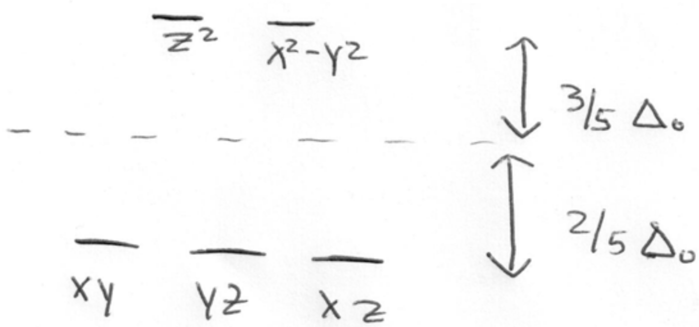
Short Answer Question #3 [15 points]

(a) (8 points) Sketch the energy levels of the 5 atomic 3d orbitals when they are in an octahedral field of negatively charged ligands. Label the energy levels, making the z axis axial and in the equatorial plane, have 2 ligands symmetrically positioned on both the x and the y axes. Show clearly which d orbitals have equal energies and do not, and also show the energies relative to a uniform negative background in terms of the splitting, Δ_o



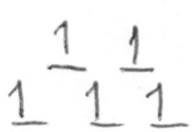
+2 pts 3 and 2 energy levels

+2 pts xy, yz, xz labels

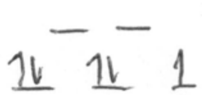
+2 pts z², x²-y² labels

+2 pts for correct energy level splitting

(b) (7 points) The ferric Fe^{3+} ion (the oxidation state found in rust) has 5 3d electrons. How many unpaired electrons are possible in the case of both small and large values of Δ_o? Predict the likely number of unpaired electrons for the $[Fe(CN)_6]^{3-}$ complex, giving a clear reason for your answer.



+2pts 5 unpaired e's for small Δ_o



+2 pts 1 unpaired e's for large Δ_o

+3 pts for identifying CN as a strong field ligand, resulting in 1 unpaired e's

B