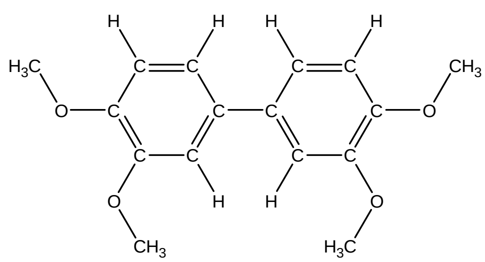
 Name: ____________________

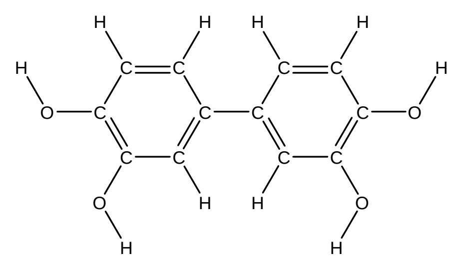
EXAM III – Oct. 31, 2019

You may work until 10:50 to complete this exam. Please show all work in the space provided or on the attached scratch page. Remember to report your final answers with the correct number of significant figures, as appropriate. A Periodic Table, a table of thermodynamic data, and a sheet of helpful constants, conversion factors and equations are provided for your use. GOOD LUCK!!

1. (11 pts) Dr. Hanna and I are working with our research students to design and evaluate compounds to prevent a protein-aggregation process involved in Alzheimer's disease. Two compounds made by a Winthrop chemistry student are shown below. Note that (1) **they differ only in the presence of O-CH_3 versus O-H groups** and (2) that **lone pairs are not shown**.



I



II

   a. Choose either one of the structures above and show how this compound engages in **hydrogen bonding with water** molecules. Be sure to clearly show the atoms involved in these interactions.

   b. One of the two compounds shown dissolves in water much more readily than the other. **Which one do you think is more soluble in water** and **how can this be explained** on the basis of intermolecular forces?

2. (36 pts) The U.S. produces approximately 2.6 billion gallons of methanol (CH_3OH) each year. It is used in fuels, as a solvent for perfumes and dyes, and in the preparation of a wide range of other chemicals – formaldehyde, plastics, paints, explosives, etc. A common preparation method involves reacting carbon monoxide and hydrogen gas as shown below:

$$CO\,(g) + 2\,H_2\,(g) \rightarrow CH_3OH\,(g)$$

The following questions are related to this reaction (or these substances). **Note that your answer to each part is independent of the others.**

Problem 2, continued: $CO\ (g) + 2\ H_2\ (g) \rightarrow CH_3OH\ (g)$

a. (8 pts) Which of the two reactants do you expect to have the **higher molar entropy** at 25 °C? **Briefly explain** your choice, being sure to specifically discuss **intermolecular forces** **and at least one other factor** influencing molecular entropy.

b. (4 pts) Suppose that you react 1 mole of CO with 2 moles of H_2. Which reactant has the greater **partial pressure**? How do you know?

c. (4 pts) If all three gases are present in a mixture at 25 °C, which molecules are moving at the **fastest average speed**? How do you know?

d. (10 pts) Using the thermodynamic data provided (p. 5), please **calculate** $\Delta H°$ for this reaction in **kJ per mole of** CH_3OH formed. Is the reaction **endothermic or exothermic**?

e. (10 pts) Suppose that an engineer in a chemical plant performs this reaction in a 1500.0-liter stainless steel vat at 25.0 °C and determines the pressure of methanol to be 25.4 atm. **How many moles** of CH_3OH were formed?

3. (24 pts) The questions below relate to the following reaction:

$$P_4O_{10}\ (s) + 6\ PCl_5\ (g) \rightarrow 10\ Cl_3PO\ (g) \qquad \mathbf{\Delta H_{rxn} = ???}$$

a. Please use the thermodynamic data below to **determine ΔH_{rxn}** for this process.

$$P_4\ (s) + 6\ Cl_2\ (g) \rightarrow 4\ PCl_3\ (g) \qquad \Delta H = -1225.6\ kJ$$

$$P_4\ (s) + 5\ O_2\ (g) \rightarrow P_4O_{10}\ (s) \qquad \Delta H = -2967.3\ kJ$$

$$PCl_3\ (g) + Cl_2\ (g) \rightarrow PCl_5\ (g) \qquad \Delta H = -84.2\ kJ$$

$$PCl_3\ (g) + \tfrac{1}{2}\ O_2\ (g) \rightarrow Cl_3PO\ (g) \qquad \Delta H = -285.7\ kJ$$

b. How much heat is absorbed or released when 50.0 g of PCl_5 reacts completely?

4. (22 pts) The over-the-counter remedy called “milk of magnesia” contains magnesium hydroxide, which neutralizes hydrochloric acid in the stomach. Suppose that you carry out the following reaction in a coffee-cup calorimeter to determine the heat flow involved:

$$2\ HCl\ (aq)\ +\ Mg(OH)_2\ (aq)\ \rightarrow\ MgCl_2\ (aq)\ +\ 2\ H_2O\ (l)$$

You add 250.0 mL of 4.00 M HCl to enough $Mg(OH)_2$ to make 500.0 total grams of solution. Initially, you measure a temperature of 23.6 °C; after reaction is complete, the temperature is 50.3 °C. Calculate ΔH_{rxn} in kJ per mole of $MgCl_2$ formed. The specific heat of solution 4.18 J/g °C. [**Hint:** Start by calculating the heat of reaction.]

5. (12 pts) Another important industrial process is the production of lime (a.k.a. calcium oxide, CaO) from limestone (calcium carbonate, $CaCO_3$); the US produces approximately 20 million metric tons per year. Under typical industrial conditions, ΔH_{rxn} = +178 kJ for this process.

$$CaCO_3\ (s)\ \rightarrow\ CaO\ (s)\ +\ CO_2\ (g) \qquad \Delta H = +178\ kJ$$

a. Please **predict the sign of ΔS** for this reaction. **Briefly explain** your reasoning. [**Note: <u>No calculations</u>** are needed here.]

b. Under what temperature conditions do you expect this process to be **spontaneous**? (Choose from: **No T, Low T, High T,** or **All T**). Explain your reasoning. You should refer to a mathematical equation in your answer, but you need **not** calculate anything.

Thermodynamic Data:

Substance	ΔH°_f (kJ/mol)
CH_3OH (*g*)	-201.0
CO (*g*)	-110.5
H_2 (*g*)	0

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If there is material to be graded here, make sure that it is clearly labeled, and that your name is written on top of this page.

Constants, Conversion Factors and Equations

Constants and Conversion Factors:

$h = 6.626 \times 10^{-34}$ J·s

$c = 2.9979 \times 10^{8} \frac{\text{m}}{\text{s}}$

$1\text{ J} = 1 \frac{\text{kg}*\text{m}^2}{\text{s}^2}$

$N_A = 6.022 \times 10^{23}$

$R = 0.08206 \frac{\text{L}*\text{atm}}{\text{mol}*\text{K}}$

1 cal = 4.184 J = 1×10^{-3} Cal

1 atm = 760 Torr = 760 mm Hg = 1.013 bar

Equations:

$d = \frac{m}{\text{V}}$

$\nu = \frac{c}{\lambda}$

$E_{\text{photon}} = h\nu$

E_K (ejected electron) = $E_{\text{photon}} - \phi$

$\Delta E = -2.18 \times 10^{-18}\text{J}\left(\frac{1}{\text{n}_\text{f}^2} - \frac{1}{\text{n}_\text{i}^2}\right)$

$E_{\text{photon}} = |\Delta E|$

$\lambda_{\text{matter}} = \frac{h}{m\text{v}}$

$M_\text{i}V_\text{i} = M_\text{f}V_\text{f}$

$PV = nRT$

$PM = dRT$

$P_A = \chi_A P_{\text{total}}$

$\chi_A = \frac{\text{n}_A}{\text{n}_{\text{total}}}$

$\text{E}_\text{K} = \frac{1}{2}\text{mv}^2$

$\overline{\text{E}}_\text{K} = \frac{3}{2}\text{RT}$

$\text{v}_{\text{rms}} = \sqrt{\frac{3\,\text{RT}}{\text{M}}}$

$\Delta G = \Delta \text{H} - \text{T}\Delta \text{S}$

$\Delta S°_{\text{rxn}} = \Sigma[\text{n}S°_m \text{ (products)}] - \Sigma[\text{n}S°_m \text{ (reactants)}]$ (similar for $\Delta \text{G}°_f$, $\Delta \text{H}°_f$)

$q = mC_s\Delta T$

$q_{\text{rxn}} = -q_{\text{soln}}$

$\Delta H = q_P$

Main groups — Transition metals — Main groups

1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8	9 8B	10	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1 **H** 1.00794																	2 **He** 4.00260
3 **Li** 6.941	4 **Be** 9.01218											5 **B** 10.81	6 **C** 12.011	7 **N** 14.0067	8 **O** 15.9994	9 **F** 18.998403	10 **Ne** 20.1797
11 **Na** 22.98977	12 **Mg** 24.305											13 **Al** 26.98154	14 **Si** 28.0855	15 **P** 30.97376	16 **S** 32.066	17 **Cl** 35.453	18 **Ar** 39.948
19 **K** 39.0983	20 **Ca** 40.078	21 **Sc** 44.9559	22 **Ti** 47.88	23 **V** 50.9415	24 **Cr** 51.996	25 **Mn** 54.9380	26 **Fe** 55.847	27 **Co** 58.9332	28 **Ni** 58.69	29 **Cu** 63.546	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.61	33 **As** 74.9216	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.80
37 **Rb** 85.4678	38 **Sr** 87.62	39 **Y** 88.9059	40 **Zr** 91.224	41 **Nb** 92.9064	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.9055	46 **Pd** 106.42	47 **Ag** 107.8682	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.710	51 **Sb** 121.757	52 **Te** 127.60	53 **I** 126.9045	54 **Xe** 131.29
55 **Cs** 132.9054	56 **Ba** 137.33	57 ***La** 138.9055	72 **Hf** 178.49	73 **Ta** 180.9479	74 **W** 183.85	75 **Re** 186.207	76 **Os** 190.2	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.9665	80 **Hg** 200.59	81 **Tl** 204.383	82 **Pb** 207.2	83 **Bi** 208.9804	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** 226.0254	89 **†Ac** 227.0278	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (263)	107 **Bh** (262)	108 **Hs** (265)	109 **Mt** (266)	110 **Uun**	111 **Uuu**	112 **Uub**		114 **Uuq**		116 **Uuh**		

*Lanthanide series	58 **Ce** 140.12	59 **Pr** 140.9077	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.9254	66 **Dy** 162.50	67 **Ho** 164.9304	68 **Er** 167.26	69 **Tm** 168.9342	70 **Yb** 173.04	71 **Lu** 174.967
†Actinide series	90 **Th** 232.0381	91 **Pa** 231.0359	92 **U** 238.0289	93 **Np** 237.048	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (260)