Chem 105 Exam 4 Name _______________

This exam is schedule for 75 minutes and I anticipate it to take the full time allotted. You are free to leave if you finish. In multiple part problems, points awarded will not be penalized for incorrect answer on previous parts, so simply **move on if you get stuck on one part**. If you need to, make up an answer for the previous part. Always neatly show work for partial credit.

1. Define the first and second laws of thermodynamics and explain what impact they have on the important concepts of thermodynamics that we have discussed in class.

2. Coal power plants are not 100% efficient; that is, not all of the energy produced from the combustion reaction results in usable energy.
   a. The combustion of coal is shown below. Is this reaction endothermic or exothermic? Explain your choice.

$$C\ (s) + O_2\ (g) \rightleftharpoons CO_2\ (g)$$

   b. What happens to the rest of the energy?

   c. Clearly explain how this is related to thermodynamics.

3. $\Delta S_{vaporization} > \Delta S_{fusion}$; Explain why this statement is true.

4. Which direction does a reaction “shift” when Q > K. **You must clearly explain your choice to receive full credit.**

Reactants Products

What is the sign of ΔG when Q < K ? positive negative

5. Explain why each of the following statements are false.
    a. A spontaneous reaction occurs when energy is consumed by a system.
    b. Liquid water has a formation enthalpy of zero ($\Delta H_f^0 = 0$).
    c. Br_2 (*l*) has a standard molar entropy of zero ($S^0 = 0$)
    d. Endothermic reactions are never spontaneous.
    e. Equilibrium occurs when the concentration of products and reactants are equal.

6. Consider the following reactions. Which is most likely to have a **negative** ΔS? You must clearly explain your answer to receive credit.

CO_2 (g) + H_2O (*l*) $\rightleftharpoons$ H_2CO_3 (aq)

2 C_8H_{18} (*l*) + 25 O_2 (g) $\rightleftharpoons$ 16 CO_2 (g) + 18 H_2O (g)

7. The synthesis of NO occurs according to the following reaction where Kc = 7.5×10^{-9} M^{-1} at 1000 K.

$$N_2 (g) + 2\ O_2 (g) \rightleftharpoons 2\ NO_2 (g)$$

    a. If 1 M of each gas is mixed together at 1000 K, would the synthesis of NO_2 be spontaneous?
    b. Determine Kc for this related reaction: 2 NO_2 (g) $\rightleftharpoons$ N_2 (g) + 2 O_2 (g)
    c. Calculate Kp at 1000 K. Include the correct units.

8. Consider the following reaction:

$$6\ HCl\ (g) + 2\ As\ (s) \rightleftharpoons 2\ AsCl_3\ (l) + 3\ H_2\ (g)$$

a. For each of the following, determine if the equilibrium will shift. If so, determine if products or reactants will be formed.
    i. Magnesium is added
    ii. HCl is added.
    iii. The volume of the flask is decreased.

b. Using the information available at the back of the exam, calculate $\Delta G°$ and $\Delta H°$.

$\Delta G°$ = ___________

$\Delta H°$ = ___________

c. What is the equilibrium constant at 25 °C?

d. Calculate $\Delta S°$

e. Calculate ΔG if 0.4 atm of CO, 2.5 atm of CO_2, 14 g of S, and 0.98 atm of CS_2 are added to a reaction flask at 25 °C.

9. Consider the following reaction.

$$3\ F_2\ (g) + N_2\ (g) \rightleftharpoons 2\ NF_3\ (g)$$

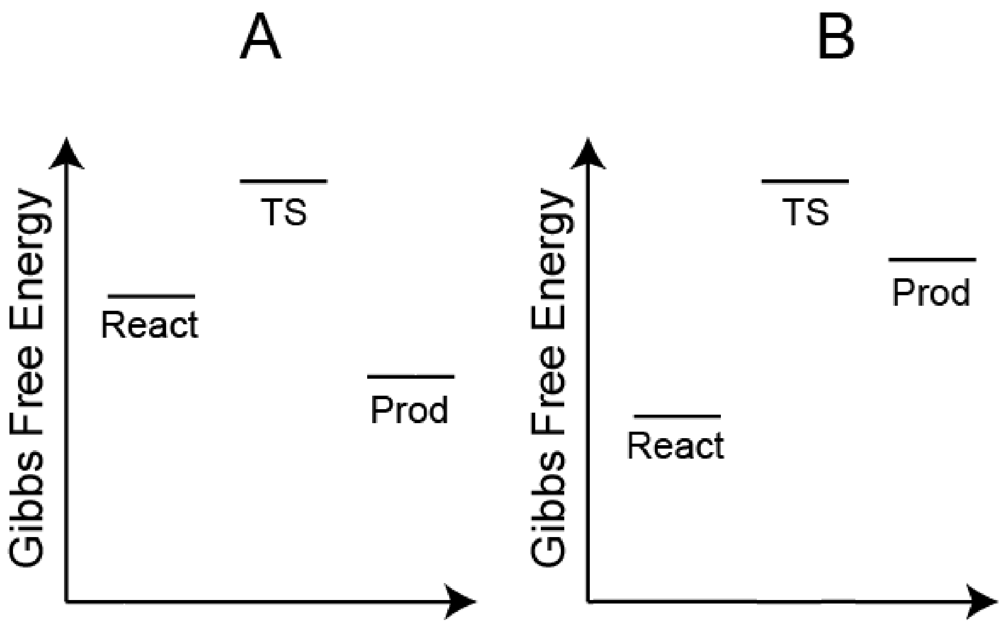
a. 2 atm of F_2 and 1 atm of N_2 are combined in a sealed reaction flask at 100 °C. Once equilibrium has been reached, the pressure is the flask is 1.706 atm. Determine the equilibrium constant at this temperature.

b. When the temperature is raised to 200 °C, the pressure of F_2 decreases to 0.01 atm.

i. Is this reaction endothermic or exothermic? Justify your selection.

ii. Optional (bonus): calculate ΔH.

10. Consider the two reaction coordinates below. Answer each of the following questions. **If it is not possible to determine, say that. Partial credit will be considered if your answer is explained.**



a. Which reaction is spontaneous?

b. Which reaction has a larger equilibrium constant?

c. Which reaction has a larger rate constant?

d. Which of these reactions is endothermic?

e. Which reaction might have $\Delta H > 0$ and $\Delta S < 0$?

11. **Complete one of the problems on this page**. You can answer more for extra credit. Please use the next page to show your work if you need more space.

a. Determine the total pressure at equilibrium if 14 grams of carbon, 1.82 atm of H_2, and 2.33 atm of CH_4 are added to a reaction flask at 500 °C.

$$C(s) + 2\ H_2\ (g) \rightleftharpoons CH_4\ (g) \qquad K_p = 2690\ atm^{-1} \text{ at } 500\ °C$$

b. Using the information in the table below, determine the heat capacity of solid CS_2 if 2.34 kJ of heat is released when 10 grams of liquid CS_2 is cooled from 46.3 °C to -150 °C.

c. ΔS_{vap} of CS_2 is 86.55 J mol^{-1} K^{-1}. Using the information in the table below, determine the boiling temperature.

Thermodynamic values for CS_2

T_b (˚C)	T_m (˚C)	ΔH_{fusion} (kJ/mol)	$\Delta H_{vaporization}$ (kJ/mol)	C (solid) J / (mol K)	C (liquid) J / (mol K)	C (gas) J / (mol K)
	-110.8	4.39	27.65		78.99	46.55

d. 1368 kJ of heat is required to decompose 112.04 grams of CO (g). Noting that the bond enthalpy of a CO triple bond is 1072 kJ mol^{-1}, calculate the bond enthalpy of a CO double bond.

$$2\ CO\ (g) \rightleftharpoons C(s) + CO_2\ (g)$$

e. Incomplete combustion of natural gas produces carbon monoxide and water vapor (see unbalanced reaction below).

$$CH_4\ (g) + O_2\ (g) \rightleftharpoons CO\ (g) + H_2O\ (g)$$

Determine $\Delta H°$ for this reaction from the data below:

$$CH_4\ (g) + 2\ O_2\ (g) \rightleftharpoons CO_2\ (g) + 2\ H_2O\ (g) \qquad \Delta H° = -802\ kJ\ mol^{-1}$$

$$2\ CO\ (g) + O_2\ (g) \rightleftharpoons 2\ CO_2\ (g) \qquad \Delta H° = -566\ kJ\ mol^{-1}$$

f. Using the information at the back of the exam, determine the temperature that is needed to make this reaction spontaneous.

$$6\ HCl\ (g) + 2\ As\ (s) \rightleftharpoons 2\ AsCl_3\ (s) + 3\ H_2\ (g)$$

Periodic Table of the Elements

Average relative masses are rounded to two decimal places.

All average masses are to be treated as measured quantities, and subject to significant figure rules.

Key: Element Name → Mercury; Atomic Number → 80; Symbol → **Hg**; Average Mass → 200.59; Electronegativity → 1.9

1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Hydrogen 1 **H** 1.01 2.1																		Helium 2 **He** 4.00 ---
Lithium 3 **Li** 6.94 1.0	Beryllium 4 **Be** 9.01 1.5												Boron 5 **B** 10.81 2.0	Carbon 6 **C** 12.01 2.5	Nitrogen 7 **N** 14.01 3.0	Oxygen 8 **O** 16.00 3.5	Fluorine 9 **F** 19.00 4.0	Neon 10 **Ne** 20.18 ---
Sodium 11 **Na** 22.99 0.9	Magnesium 12 **Mg** 24.31 1.2												Aluminum 13 **Al** 26.98 1.5	Silicon 14 **Si** 28.09 1.8	Phosphorus 15 **P** 30.97 2.1	Sulfur 16 **S** 32.07 2.5	Chlorine 17 **Cl** 35.45 3.0	Argon 18 **Ar** 39.95 ---
Potassium 19 **K** 39.10 0.8	Calcium 20 **Ca** 40.08 1.0		Scandium 21 **Sc** 44.96 1.3	Titanium 22 **Ti** 47.88 1.5	Vanadium 23 **V** 50.94 1.6	Chromium 24 **Cr** 52.00 1.6	Manganese 25 **Mn** 54.94 1.5	Iron 26 **Fe** 55.85 1.8	Cobalt 27 **Co** 58.93 1.8	Nickel 28 **Ni** 58.69 1.8	Copper 29 **Cu** 63.55 1.9	Zinc 30 **Zn** 65.39 1.6	Gallium 31 **Ga** 69.72 1.6	Germanium 32 **Ge** 72.61 1.8	Arsenic 33 **As** 74.92 2.0	Selenium 34 **Se** 78.96 2.4	Bromine 35 **Br** 79.90 2.8	Krypton 36 **Kr** 83.80 3.0
Rubidium 37 **Rb** 85.47 0.8	Strontium 38 **Sr** 87.62 1.0		Yttrium 39 **Y** 88.91 1.2	Zirconium 40 **Zr** 91.22 1.4	Niobium 41 **Nb** 92.91 1.6	Molybdenum 42 **Mo** 95.94 1.8	Technetium 43 **Tc** (98) 1.9	Ruthenium 44 **Ru** 101.07 2.2	Rhodium 45 **Rh** 102.91 2.2	Palladium 46 **Pd** 106.42 2.2	Silver 47 **Ag** 107.87 1.9	Cadmium 48 **Cd** 112.41 1.7	Indium 49 **In** 114.82 1.7	Tin 50 **Sn** 118.71 1.8	Antimony 51 **Sb** 121.76 1.9	Tellurium 52 **Te** 127.60 2.1	Iodine 53 **I** 126.90 2.5	Xenon 54 **Xe** 131.29 2.6
Cesium 55 **Cs** 132.91 0.7	Barium 56 **Ba** 137.33 0.9	57-70 *	Lutetium 71 **Lu** 174.97 1.1	Hafnium 72 **Hf** 178.49 1.3	Tantalum 73 **Ta** 180.95 1.5	Tungsten 74 **W** 183.84 1.7	Rhenium 75 **Re** 186.21 1.9	Osmium 76 **Os** 190.23 2.2	Iridium 77 **Ir** 192.22 2.2	Platinum 78 **Pt** 195.08 2.2	Gold 79 **Au** 196.97 2.4	Mercury 80 **Hg** 200.59 1.9	Thallium 81 **Tl** 204.38 1.8	Lead 82 **Pb** 207.20 1.8	Bismuth 83 **Bi** 208.98 1.9	Polonium 84 **Po** (209) 2.0	Astatine 85 **At** (210) 2.2	Radon 86 **Rn** (222) 2.4
Francium 87 **Fr** (223) 0.7	Radium 88 **Ra** (226) 0.9	89-102 **	Lawrencium 103 **Lr** (262) ---	Rutherfordium 104 **Rf** (261) ---	Dubnium 105 **Db** (262) ---	Seaborgium 106 **Sg** (266) ---	Bohrium 107 **Bh** (264) ---	Hassium 108 **Hs** (269) ---	Meitnerium 109 **Mt** (268) ---	Darmstadtium 110 **Ds** (271) ---	Roegentium 111 **Rg** (272) ---	Copernicium 112 **Cn** (277) ---	Ununtrium 113 **Uut** (284) ---	Flerovium 114 **Fl** (289) ---	Ununpentium 115 **Uup** (288) ---	Livermorium 116 **Lv** (293) ---	Ununseptium 117 **Uus** (294) ---	Ununoctium 118 **Uuo** (294) ---

*lanthanides	Lanthanum 57 **La** 138.91 1.1	Cerium 58 **Ce** 140.12 1.1	Praseodymium 59 **Pr** 140.91 1.1	Neodymium 60 **Nd** 144.24 1.1	Promethium 61 **Pm** (145) 1.1	Samarium 62 **Sm** 150.36 1.2	Europium 63 **Eu** 151.97 1.1	Gadolinium 64 **Gd** 157.25 1.2	Terbium 65 **Tb** 158.93 1.1	Dysprosium 66 **Dy** 162.50 1.2	Holmium 67 **Ho** 164.93 1.2	Erbium 68 **Er** 167.26 1.2	Thulium 69 **Tm** 168.93 1.3	Ytterbium 70 **Yb** 173.04 1.1
**actinides	Actinium 89 **Ac** (227) 1.1	Thorium 90 **Th** 232.04 1.3	Protactinium 91 **Pa** 231.04 1.5	Uranium 92 **U** 238.03 1.4	Neptunium 93 **Np** (237) 1.4	Plutonium 94 **Pu** (244) 1.3	Americium 95 **Am** (243) 1.3	Curium 96 **Cm** (247) 1.3	Berkelium 97 **Bk** (247) 1.3	Californium 98 **Cf** (251) 1.3	Einsteinium 99 **Es** (252) 1.3	Fermium 100 **Fm** (257) 1.3	Mendelevium 101 **Md** (258) 1.3	Nobelium 102 **No** (259) 1.3

	ΔH_f^0 kJ mol^{-1}	ΔG_f^0 kJ mol^{-1}
$AsCl_3$ (l)	-305.2	-259.0
HCl (g)	-110.5	-137.2

Equations

$\Delta G = \Delta H - T\Delta S$ $\Delta G^0 = -RTlnK$ $\Delta G = \Delta G^o + RTlnQ$

$\Delta U = q + w$ $w = -p\Delta V$ $\Delta G = -T\Delta S_{universe}$

$\Delta H = C_p\Delta T$ $ln\frac{K_2}{K_1} = \frac{\Delta H}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$ R = 0.08206 L atm mol^{-1} K^{-1} R = 8.314 J mol^{-1} K^{-1}

Kp = Kc $(RT)^{\Delta ngas}$ $x = \frac{-b\pm\sqrt{b^2-4ac}}{2a}$