

## Quiz 8 – Due at the start of class Monday, November 5, 2018

Complete the following problems. Write your final answers in the blanks provided. You must show your work to receive full credit. Show your answers to the correct number of significant figures with the correct units.

## Rules for this take-home quiz.

**DO NOT OPEN THE QUIZ UNTIL YOU ARE READY TO TAKE IT!**

- You may allocate a maximum of **50 continuous minutes** for this quiz, split in to two 25-minute segments.
- For the first 25-minute segment, you will take the quiz using only the materials on these pages, a calculator and a **pencil**. Treat this time as though you were taking the quiz in the classroom. You may not use your book, notes, electronic sources or anyone else to help. Record the start and end of the first 25 minutes below.
- For the second 25 minutes, you may use your book, notes or electronic resources to make any corrections to your work. **Make these corrections in blue or red pen.** You **MAY NOT** ask anyone else for help. Record the end of the second 25 minute block below.
- Once you have completed the quiz, sign below to affirm that the quiz was taken following the rules above. This signature is your pledge that the quiz was completed in an ethical manner!

Start time: \_\_\_\_\_ End of 1<sup>st</sup> 25 minutes: \_\_\_\_\_ End of 2<sup>nd</sup> 25 minutes: \_\_\_\_\_

Signature \_\_\_\_\_ Date \_\_\_\_\_

**Periodic Table of the Elements**

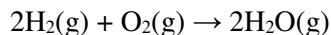
1 IA H Hydrogen 1.008	2 IIA He Helium 4.003																
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305	13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948										
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.796
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.294
55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71 Lanthanide Series	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103 Actinide Series	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [278]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [280]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [289]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]
		57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.243	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.055	71 Lu Lutetium 174.967	
		89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]	

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## Possibly Useful Information

$K = ^\circ\text{C} + 273.15$	$q = mc\Delta T$	$q = n_{LR}\Delta H_{rxn}$	$q = m\Delta H$
$\Delta S_{universe} = \Delta S_{system} - \Delta S_{surr}$		$\Delta G = \Delta H - T\Delta S$	$\Delta S_{surr} = -\Delta H_{sys}/T$

1. From the information in the table below, combine the reactions as necessary to determine the  $\Delta G^\circ$  for the following reaction. (8 pts)



Reaction	$\Delta G^\circ$
$\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}(\text{g})$	+173.1 kJ
$4\text{NH}_3(\text{g}) + 5\text{O}_2(\text{g}) \rightarrow 4\text{NO}(\text{g}) + 6\text{H}_2\text{O}(\text{g})$	-1010.5 kJ
$\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$	-33.0 kJ
$2\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{N}_2\text{O}(\text{g})$	+208.4 kJ

First combine reactions to get appropriate compounds as reactants and products, cancelling out redundant species.

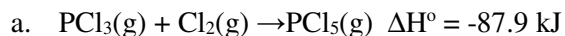
$2[2\text{NO}(\text{g}) \rightarrow \text{N}_2(\text{g}) + \text{O}_2(\text{g})]$	-2(+173.1 kJ)
$4\text{NH}_3(\text{g}) + 5\text{O}_2(\text{g}) \rightarrow 4\text{NO}(\text{g}) + 6\text{H}_2\text{O}(\text{g})$	-1010.5 kJ
$2[\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})]$	2(-33.0kJ)
$4\text{NO} + 4\text{NH}_3 + 5\text{O}_2 + 2\text{N}_2 + 6\text{H}_2 \rightarrow 2\text{N}_2 + 2\text{O}_2 + 4\text{NO} + 6\text{H}_2\text{O} + 4\text{NH}_3$	$(-346.2 \text{ kJ}) + (-1010.5 \text{ kJ}) + (-66.0 \text{ kJ}) = -1422.7 \text{ kJ}$
$3\text{O}_2 + 6\text{H}_2 \rightarrow 6\text{H}_2\text{O}$	

Now adjust to get the appropriate coefficients for all the reactants and products

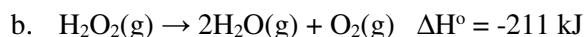
$1/3(3\text{O}_2 + 6\text{H}_2 \rightarrow 6\text{H}_2\text{O})$	$1/3(-1422.7 \text{ kJ})$
$\text{O}_2 + 2\text{H}_2 \rightarrow 2\text{H}_2\text{O}$	<b>-474.3 kJ</b>

Answer     **-474.3 kJ**    

2. For each of the reactions below, select which of the following describes the reaction and justify your assertion in a sentence or two. (a) spontaneous at all temperatures, (b) nonspontaneous at all temperatures, (c) spontaneous at high temperatures, (d) spontaneous at low temperatures, (e) unable to tell. (8 pts)

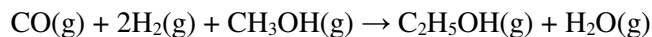


$\Delta H^\circ < 0$  and  $\Delta S^\circ < 0$  (since there are fewer moles of gas on the products side compared to the reactants side) for this reaction. Thus, this reaction is spontaneous at low temperatures and non-spontaneous at high temperatures.



$\Delta H^\circ < 0$  and  $\Delta S^\circ > 0$  (since there are more moles of gas on the products side compared to the reactants side) for this reaction. Thus, this reaction is spontaneous at all temperatures since  $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$  and  $(-) - (+)(-) = (-)$ .

3. A possible reaction for converting methanol to ethanol is



This reaction is not spontaneous at all temperatures. Use the information below to calculate  $\Delta G^\circ$  for the reaction and determine the temperature where the sign of  $\Delta G^\circ$  changes. (9 pts)

Compound	$\Delta H^\circ_f$ , kJ mol <sup>-1</sup>	$\Delta G^\circ_f$ , kJ mol <sup>-1</sup>	$S^\circ_f$ , J mol <sup>-1</sup> K <sup>-1</sup>
CO(g)	-110.5	-137.2	+197.7
H <sub>2</sub> (g)	0	0	+130.7
CH <sub>3</sub> OH(g)	-200.7	-162.0	+239.8
C <sub>2</sub> H <sub>5</sub> OH(g)	-235.1	-168.5	+282.7
H <sub>2</sub> O(g)	-241.8	-228.6	+188.8

$$\begin{aligned}\Delta H^\circ &= [\Delta H^\circ_f(\text{C}_2\text{H}_5\text{OH(g)}) + \Delta H^\circ_f(\text{H}_2\text{O(g)})] - [\Delta H^\circ_f(\text{CO(g)}) + 2\Delta H^\circ_f(\text{H}_2\text{(g)}) + \Delta H^\circ_f(\text{CH}_3\text{OH(g)})] \\ \Delta H^\circ &= [-235.1 \text{ kJ} + (-241.8 \text{ kJ})] - [(-110.5 \text{ kJ}) + 2(0 \text{ kJ}) + (-200.7 \text{ kJ})] \\ \Delta H^\circ &= -165.7 \text{ kJ}\end{aligned}$$

$$\begin{aligned}\Delta S^\circ &= [S^\circ_f(\text{C}_2\text{H}_5\text{OH(g)}) + S^\circ_f(\text{H}_2\text{O(g)})] - [S^\circ_f(\text{CO(g)}) + 2S^\circ_f(\text{H}_2\text{(g)}) + S^\circ_f(\text{CH}_3\text{OH(g)})] \\ \Delta S^\circ &= [282.7 \text{ J/K} + (188.8 \text{ J/K})] - [(197.7 \text{ J/K}) + 2(130.7 \text{ J/K}) + (239.8 \text{ J/K})] \\ \Delta S^\circ &= -227.4 \text{ J/K}\end{aligned}$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ = -165.7 \text{ kJ} - (298 \text{ K})(-0.2274 \text{ kJ/K}) = -97.9 \text{ kJ}$$

Since  $\Delta S^\circ$  and  $\Delta H^\circ$  have the same sign, there must be a temperature that causes the sign of  $\Delta G^\circ$  to change. You can calculate that temperature as shown below but you did not have to.

$$\begin{aligned}0 &= \Delta H^\circ - T\Delta S^\circ \\ T &= \Delta H^\circ / \Delta S^\circ = -165.7 \text{ kJ} / (0.2274 \text{ kJ/K}) = 729 \text{ K}\end{aligned}$$

You could also have calculated  $\Delta G^\circ$  from the  $\Delta G^\circ_f$  values as shown below:

$$\begin{aligned}\Delta G^\circ &= [\Delta G^\circ_f(\text{C}_2\text{H}_5\text{OH(g)}) + \Delta G^\circ_f(\text{H}_2\text{O(g)})] - [\Delta G^\circ_f(\text{CO(g)}) + 2\Delta G^\circ_f(\text{H}_2\text{(g)}) + \Delta G^\circ_f(\text{CH}_3\text{OH(g)})] \\ \Delta G^\circ &= [-168.5 \text{ kJ} + (-228.6 \text{ kJ})] - [(-137.2 \text{ kJ}) + 2(0 \text{ kJ}) + (-162.0 \text{ kJ})] \\ \Delta G^\circ &= -97.9 \text{ kJ}\end{aligned}$$

NOTE: You could make the judgment on whether  $\Delta G^\circ$  changes sign without actually calculating  $\Delta H^\circ$  and  $\Delta S^\circ$ . Looking at the reaction, there are 5 moles of gas on the reactant side and two moles of gas on the product side, indicating the  $\Delta S^\circ$  will be negative. Since  $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ , if  $\Delta S^\circ$  is negative, the only way  $\Delta G^\circ$  could be negative as well is if  $\Delta H^\circ$  is also negative. If  $\Delta S^\circ$  and  $\Delta H^\circ$  both have the same sign, there must be a temperature where the sign of  $\Delta G^\circ$  changes.

$$\Delta G^\circ = -97.9 \text{ kJ}$$

Answer \_\_\_\_\_ T = 729 K (456°C) \_\_\_\_\_