Dougherty Valley HS AP Chemistry
Thermodynamics – Extra Practice Free-Energy and Spontaneity

WORKSHEET #4*

Name: **Date:** **Period:** **Seat #:**

Show all work. Complete the following on binder paper and BOX your final answers.

[1] Using enthalpies of formation (Appendix Four), calculate ΔH° for the following reaction at 25°C. Also calculate ΔS° for this reaction from standard entropies at 25°C. Use these values to calculate ΔG° for the reaction at this temperature.
-1453.2 KJ, -162 KJ, -1404.9 KJ

$$2CH_3OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 4H_2O(l)$$

[2] The free energy of formation of one mole of compound refers to a particular chemical equation. For each of the following, write that equation.
[a] NaCl (s)
[b] HCN (*l*)
[c] SO_2 (g)
[d] PH_3 (g)

[3] Calculate the standard free energy of the following reactions at 25°C, using standard free energies of formation.
[a] $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$
[b] $CaCO_3(s) + 2H^+(aq) \rightarrow Ca^{2+}(aq) + H_2O(l) + CO_2(g)$

	ΔH_f°	ΔG_f°	ΔS°
Ca^{2+}	-542.96	-533.04	-55.2

[4] On the basis of ΔG° for each of the following reactions, decided whether the reaction is spontaneous or non-spontaneous as written. Or, if you expect an equilibrium mixture with significant amounts of both reactants and products, say so.
[a] $SO_2 + 2H_2S \rightarrow 3S + 2H_2O$ ΔG° = -91 kJ
[b] $2H_2O_2 \rightarrow O_2 + 2H_2O$ ΔG° = -211 kJ
[c] $HCOOH \rightarrow CO_2 + H_2$ ΔG° = 119 kJ
[d] $I_2 + Br_2 \rightarrow 2IBr$ ΔG° = 7.5 kJ
[e] $NH_4Cl \rightarrow NH_3 + HCl$ ΔG° = 92 kJ

[5] Calculate ΔH° and ΔG° for the following reactions at 25°C, using thermodynamic data from your books Appendix; interpret the signs of ΔH° and ΔG°.
[a] $Al_2O_3 + 2Fe \rightarrow Fe_2O_3 + 2Al$ (851 kJ; 838 kJ)
[b] $COCl_2 + H_2O \rightarrow CO_2 + 2HCl$; [$COCl_2$: ΔH_f° = -220KJ/mol and ΔG_f° = -206KJ/mol] (-72 kJ; -142kJ)

[6] Using enthalpies of formation (appendix four), calculate ΔH° for the following reactions at 25°C. Also calculate ΔS° for this reaction from standard entropies at 25 C. Use these values to calculate ΔG° for the reaction at this temperature.

$$4HCN + 5O_2 \rightarrow 2H_2O + 4CO_2 + 2N_2$$

[7] The free energy of formation of one mole of compound refers to a particular chemical equation. For each of the following, write that equation.
[a] CaO(s)
[b] CH_3NH_2 (g)
[c] CS_2 (*l*)
[d] P_4O_{10} (s)

[8] Calculate the standard free energy of the following reactions at 25 C, using standard free energies of formation from the appendix.
[a] $C_2H_4(g) + O_2(g) \rightarrow 2CO_2(g) + 2H_2O(g)$
[b] $Na_2CO_3(s) + H^+(aq) \rightarrow 2Na^+(aq) + HCO_3^-(aq)$

	ΔH_f°	ΔG_f°	ΔS°
HCO_3^-	-691.11	-587.06	95.0

[9] For each of the following reactions, state whether the reaction is spontaneous or non-spontaneous as written or is easily reversible (that is, is a mixture with significant amounts of reactants and products)

[a] $HCN + 2H_2 \rightarrow CH_3NH_2$ $\Delta G° = -92$ kJ

[b] $N_2 + O_2 \rightarrow 2NO$ $\Delta G° = 173$ kJ

[c] $2NO + 3H_2O \rightarrow 2NH_3 + \frac{5}{2}O_2$ $\Delta G° = 479$ kJ

[d] $H_2 + Cl_2 \rightarrow 2HCl$ $\Delta G° = -191$ kJ

[e] $H_2 + I_2 \rightarrow 2HI$ $\Delta G° = 2.6$ kJ

[10] Calculate $\Delta H°$ and $\Delta G°$ for the following reactions at 25°C, using thermodynamic data from Appendix; interpret the signs of $\Delta H°$ and $\Delta G°$.

[a] $2PbO + N_2 \rightarrow 2Pb + 2NO$

[b] $CS_2 + 2H_2O \rightarrow CO_2 + 2H_2S$; CS_2: ΔH_f° = 87.9kJ and ΔG_f° = 63.6kJ

[11] Give the expression for the thermodynamic equilibrium constant for each of the following reactions:

[a] $CO(g) + H_2O(g) \rightarrow CO_2(g) + H_2(g)$

[b] $Mg(OH)_2(s) \rightarrow Mg^{2+}(aq) + 2OH^-(aq)$

[c] $2Li(s) + 2H_2O(l) \rightarrow 2Li^+(aq) + 2OH^-(aq) + H_2(g)$

[12] What is the standard free energy change $\Delta G°$ at 25°C for the following reaction? Obtain necessary information from the Appendix: (-190.6kJ, $2.5E^{-33}$)

$H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$

What is the value of the thermodynamic equilibrium constant K?

[13] Calculate the standard free energy change and the equilibrium constant K_p for the following reaction at 25°C. See appendix four for data. (-142.2kJ, $8.3E^{24}$) – From another source **$CO(g) + 3H_2(g) \rightarrow CH_4(g) + H_2O(g)$**

[16] Obtain the equilibrium constant K_c at 25° C from the free-energy change for the reaction:

$Mg(s) + Cu^{2+} \rightarrow Mg^{2+}(aq) + Cu(s)$

(-520.99kJ, $1.88E^{91}$)

	ΔH_f°	ΔG_f°	ΔS°
Cu^{2+}	64.39	64.98	-98.7
Mg^{2+}	-461.96	-456.01	-118

[17] What is the standard free-energy change $\Delta G°$ at 25°C for the following reaction? Obtain necessary information from Appendix: **$C(graphite) + O_2(g) \rightarrow CO_2(g)$** Calculate the value of the equilibrium constant K.

[18] Calculate the standard free energy change and the equilibrium constant K_p for the following reaction at 25°C. See appendix for data. **$CO(g) + 2H_2(g) \rightarrow CH_3OH(g)$**

[19] Calculate the equilibrium constant K_c at 25 C from the free-energy change for the reaction:

$Zn(s) + Cu^{2+} \rightarrow Zn^{2+} + Cu(s)$

	ΔH_f°	ΔG_f°	ΔS°
Cu^{2+}	64.39	64.98	-98.7
Zn^{2+}	-152.4	-147.21	-106.5