Department of Chemistry
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Free Energy – Supplemental Worksheet

1. Calculate $\Delta S_{universe}$ after the completion of the following reaction:

$2NiS(s) + 3O_2(g) \rightarrow 2SO_2(g) + 2NiO(s)$ at 25 °C $\Delta H = -890$ kJ

Substance	S (J/Kmole)
SO_2	248
NiO	38
O_2	205
NiS	53

$\Delta S_{sys} = [2(248) + 2(38)] - [2(53) + 3(205)] = -149$ J/K
$\Delta S_{surr} = -\Delta H/T = -(-890$ kJ$)/298$ K $= 3$ kJ/K $= 3000$J/K
$\Delta S_{universe} = \Delta S_{sys} + \Delta S_{surr} = -149$ J/K $+ 3000$ J/K $= 2851$ J/K

2. Determine the ΔG when:

$\Delta S_{universe} = 1303$ J/K
$\Delta S_{surr} = 1.300$ kJ/K
T = 25 °C

$\Delta S_{univ} = \Delta S_{sys} + \Delta S_{surr}$
$\Delta S_{sys} = \Delta S_{univ} - \Delta S_{surr} = 1303$ J/K $- 1300$ J/K $= 3$ J/K
$\Delta S_{surr} = -\Delta H/T$
$\Delta H = -T\Delta S_{surr} = -(298K)(1.3$ kJ/K$) = -387.4$ kJ
$\Delta G = \Delta H - T\Delta S_{sys} = -387.4$ kJ $- (298K)(.003$ kJ/K$) = -388.3$ kJ

3. Determine the minimum temperature for a reaction with $\Delta H = 271$ kJ and $\Delta S = 195$ J/K to be spontaneous.

When $\Delta G = 0$ the reaction is at equilibrium, so solve for T under these conditions.
$\Delta G = \Delta H - T\Delta S = 0$
$T = \Delta H/\Delta S = 271$ kJ $/ (0.195$ kJ/K$) = 1389.74$ K

4. Consider the reaction: $CO(g) + Cl_2(g) \rightarrow COCl_2(g)$ Calculate ΔG_{rxn} at 25 °C.

Substance	ΔH_f (kJ/mol)	S (J/ mol K)
CO	-110.5	197.6
Cl_2	0.0	223.0
$COCl_2$	-223.0	289.2

$\Delta H_{rxn} = \Sigma\Delta H_{f,products} - \Sigma\Delta H_{f,reactants}$
$\Delta H_{rxn} = [-223$ kJ/mol$] - [-110.5$ kJ/mol$] = -112.5$ kJ/mol
$\Delta S_{rxn} = \Sigma\Delta S_{m,products} - \Sigma\Delta S_{m,reactants}$
$\Delta S_{rxn} = [289.2$ J/mol K$] - [(223$ J/mol K$) + (197.6$ J/mol K$)] = -131.4$ J/ mol K
$\Delta G = \Delta H - T\Delta S$
$\Delta G = -112.5$ kJ/mol $- 298K$ (-0.1314 kJ/mol K$) = -73.34$ kJ/mol

5. Determine ΔG_f for $SO_2(g)$. Assume 25 °C for all reactions.

$\Delta H_{f,SO2}$ (g) = -297 kJ/mol $S_{m,SO2}$ (g) = 248 J/(K mol)

Then determine ΔG_{rxn} of the following reaction: ΔG_f Cu_2S (s) = -86.2 kJ/mol

$Cu_2S(s) + O_2(g) \rightarrow SO_2(g) + 2Cu(s)$

$\Delta G_{f,SO2} = \Delta H - T\Delta S = (-297\ kJ/mol) - (298K)(.248\ kJ/mol) = -370.9\ kJ/mol$
$\Delta G_{rxn} = \Sigma\Delta G_{f,products} - \Sigma\Delta G_{f,reactants}$
$\Delta G_{rxn} = -370.9\ kJ/mol - (-86.2\ kJ/mol) = -284.7\ kJ/mol$

6. Calculate ΔG° for the reactions below using the provided data. Assume 298 K is standard temperature for your calculations.

	$\Delta H°_f$ ($kJ \cdot mol^{-1}$)	$\Delta S°_m$ ($J \cdot mol^{-1} \cdot K^{-1}$)
$Ag^+(aq)$	105.6	72.68
AgCl(s)	-127.1	96.2
$C_{graphite}(s)$		5.740
CH3OH(l)	-238.7	126.8
$Cl^-(aq)$	-167.2	56.5
$H_2(g)$		130.6
$O_2(g)$		205.0

a. $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$

$\Delta H°_{rxn} = \Sigma\Delta H_{f,products} - \Sigma\Delta H_{f,reactants} = (-127.1) - (105.6 - 167.2) = -65.5\ kJ \cdot mol^{-1}$
$\Delta S°_{rxn} = \Sigma\Delta S_{m,products} - \Sigma\Delta S_{m,reactants} = (96.2) - (72.78 + 56.5) = -33.08\ J \cdot mol^{-1} \cdot K^{-1} = -0.03308 kJ \cdot mol^{-1} \cdot K^{-1}$
$\Delta G°_{rxn} = \Delta H°_{rxn} - 298 \cdot \Delta S°_{rxn} = -65.5\ kJ \cdot mol^{-1} - 298\ K \cdot -0.03308\ J \cdot mol^{-1} \cdot K^{-1} = -55.64\ kJ \cdot mol^{-1}$

b. $C_{graphite}(s) + 1/2\ O_2(g) + 2\ H_2(g) \rightarrow CH3OH(l)$

$\Delta H°_{rxn} = \Sigma\Delta H_{f,products} - \Sigma\Delta H_{f,reactants} = (-238.7) - (0) = -238.7\ kJ \cdot mol^{-1}$
$\Delta S°_{rxn} = \Sigma\Delta S_{m,products} - \Sigma\Delta S_{m,reactants} = (126.8) - (5.740 + 1/2 \cdot 205.0 + 2 \cdot 130.6) = -242.64\ J \cdot mol^{-1} \cdot K^{-1}$
$= -0.24264\ kJ \cdot mol^{-1} \cdot K^{-1}$
$\Delta G°_{rxn} = -238.7\ kJ \cdot mol^{-1} - 298\ K \cdot -0.242.64\ kJ \cdot mol^{-1} \cdot K^{-1} = -166.39\ kJ \cdot mol^{-1}$