Worksheet 2: Hess's Law, Heats of Formation, and Entropy

Helpful information for this worksheet:

Substance	ΔH_f° (kJ/mole)	S° (J/mole·K)
C (s, graphite)	?	5.686
CO (g)	-110.5	197.5
CO_2 (g)	-393.5	213.7
CH_4 (g)	-74.87	186.1
C_3H_8 (g)	-105	269.9
CH_3OH (l)	-238.6	126.8
Cl (g)	121.0	165.1
H_2 (g)	?	130.6
H_2O (l)	-285.840	69.940
H_2O (g)	-241.826	188.72
N_2 (g)	?	191.5
NO (g)	90.29	210.65
NO_2 (g)	33.2	239.9
N_2O_4 (g)	9.16	304.3
O_2 (g)	?	205.0
O_3 (g)	143	238.82

Concept questions: 6.75, 6.81, *6.129, *6.131, *6.133, *6.135, 17.27, 17.29, 17.31, 17.33, 17.45, 17.47, 17.49, *17.107, *17.109, *17.111
Hess's Law and Heats of Formation: 6.77, 6.79, 6.83, 6.85, 6.87, 6.89
Cumulative Problems: 6.97, 6.99, 6.101, 6.111, 6.121
Entropy: 17.51, 17.53

1. Determine ΔH for the decomposition of NOCl from the following data:

   $2\ NOCl\ (g) \rightarrow N_2\ (g) + O_2\ (g) + Cl_2\ (g)$ $\Delta H = ?$

   a. $\frac{1}{2}\ N_2\ (g) + \frac{1}{2}\ O_2\ (g) \rightarrow NO\ (g)$ $\Delta H = 90.3$ kJ

   b. $NO\ (g) + \frac{1}{2}\ Cl_2\ (g) \rightarrow NOCl\ (g)$ $\Delta H = -38.6$ kJ

   Which of the ΔH_{rxn} values above represent heats of formation?

2. At high temperatures, such as those in the combustion chambers of automobile engines, the following endothermic reaction occurs:

   $N_2\ (g) + O_2\ (g) \rightarrow 2\ NO\ (g)$ $\Delta H^\circ = 180$ kJ

   When NO is released into the environment, it may undergo further oxidation to NO_2 in the following exothermic reaction:

   $2\ NO\ (g) + O_2\ (g) \rightarrow 2\ NO_2\ (g)$ $\Delta H^\circ = -112$ kJ

   Is the overall reaction for the formation of NO_2 from N_2 and O_2 endothermic or exothermic? What is ΔH° for this reaction?

3. The destruction of ozone by chlorofluorocarbons (CFCs) can be described by the following reactions:

   a. $ClO\ (g) + O_3\ (g) \rightarrow Cl\ (g) + 2\ O_2\ (g)$ $\Delta H^\circ = -29.90$ kJ

   b. $2\ O_3\ (g) \rightarrow 3\ O_2\ (g)$ $\Delta H^\circ = 24.18$ kJ

   Determine the value of ΔH° for:

   $Cl\ (g) + O_3\ (g) \rightarrow ClO\ (g) + O_2\ (g)$

4. Calculate ΔH for the reaction:
   $2\ C\ (s) + H_2\ (g) \rightarrow C_2H_2\ (g)$
   given the following three chemical equations and their respective enthalpy changes:
   a. $C_2H_2\ (g) + 5/2\ O_2\ (g) \rightarrow 2\ CO_2\ (g) + H_2O\ (l)$ $\Delta H = -1299.6$ kJ
   b. $C\ (s) + O_2\ (g) \rightarrow CO_2\ (g)$ $\Delta H = -393.5$ kJ
   c. $H_2\ (g) + ½\ O_2\ (g) \rightarrow H_2O\ (l)$ $\Delta H = -285.8$ kJ
5. Use heats of formation to calculate the enthalpy of reaction for the following methane-generating reaction of methanogenic bacteria:
   $4\ H_2\ (g) + CO_2\ (g) \rightarrow CH_4\ (g) + 2\ H_2O\ (g)$
6. For each of the following compounds, write a balanced formation equation:
   a. $NH_3\ (g)$ b. $SO_2\ (g)$ c. $NH_4NO_3\ (s)$ d. $RbClO_3\ (s)$
7. In each of the following pairs, which alternative has the greater entropy:

A	**B**
pound of ice cubes	pint of water
spoonful of sugar in bowl	spoonful of sugar dissolved in coffee
cup of hot water	cup of cold water
$CH_4\ (g)$	$CF_4\ (g)$
$H_2O\ (g)$	$NH_3\ (g)$

8. Predict the sign of ΔS for each of the following processes
   a. a bricklayer builds a wall out of a random pile of bricks
   b. rake a yard full of leaves into a single pile
   c. $Ag^+\ (aq) + Cl^-\ (aq) \rightarrow AgCl\ (s)$
   d. $Zn\ (s) + 2\ HCl\ (aq) \rightarrow H_2\ (g) + ZnCl_2\ (aq)$
9. Using the standard molar entropies in the Table, calculate $\Delta S°$ values for the following atmospheric reactions, which contribute to the formation of chemical smog
   a. $N_2\ (g) + O_2\ (g) \rightarrow 2\ NO\ (g)$
   b. $2\ NO\ (g) + O_2\ (g) \rightarrow 2\ NO_2\ (g)$
   c. $NO\ (g) + ½\ O_2\ (g) \rightarrow NO_2\ (g)$
   d. $2\ NO_2\ (g) \rightarrow N_2O_4\ (g)$
10. The following reaction plays a key role in the destruction of ozone in the atmosphere. The standard entropy change ($\Delta S°$) is 19.9 J/K. Use the standard molar entropies to calculate the molar entropy value for ClO.
    $Cl\ (g) + O_3\ (g) \rightarrow ClO\ (g) + O_2\ (g)$
11. What are the signs of ΔS and ΔH for the sublimation of dry ice at 25°C?

Key:

1. -103.4 kJ 2. + 34 kJ 3. +54.08 kJ
4. +226.8 kJ 5. -165 kJ 6. a. $\frac{1}{2}\ N_2\ (g) + 3/2\ H_2\ (g) \rightarrow NH_3\ (g)$
7. B, B, A, B, B 8. -, -, -, +
9. a. 24.7 J/K, b. -146.4 J/K, c. -73.2 J/K, d. -175.5 J/K
10. $S° = 218.8$ J/mole·K
11. +, +