Exercise 6.4
Enthalpy of Formation

Name: ____________________

Date:________________ Per:________

Hess' Law can be used to determine the enthalpy of reaction for chemical reactions by using the enthalpies of formation for the component reactants and products, using the formula:

$$\Delta H^\circ_{rxn} = \Sigma\ \Delta H^\circ_{f,\ products} - \Sigma\ \Delta H^\circ_{f,\ reactants}$$

Some general rules relating to Hess' Law when calculating ΔH° for a reaction from enthalpies of formation:

- The standard enthalpy of formation for an element in its standard state is zero.
  - Standard states for most elements are their solid, monatomic state.
  - Standard states for noble gases and H_2, O_2, N_2, F_2, Cl_2 are gaseous.
  - Standard state for C(s) is graphite.
  - Standard states for Hg and Br_2 are liquid.
  - Standard state for iodine is diatomic solid (I_2).
- If you modify the coefficients of a reaction, multiply ΔH by the same factor.

Compound	ΔH_f (kJ/mol)	Compound	ΔH_f (kJ/mol)
$AlCl_3$(s)	-704.2	MnO_2(s)	-519.7
Al_2O_3(s)	-1675.7	NaCl(s)	-411.0
$Ca_3(PO_4)_2$(s)	- 4120.8	NaF(s)	-569.0
$CaSO_4$(s)	-1434.5	Na_2O(s)	-414.2
CH_4(g)	-74.8	NaOH(s)	-426.7
ClF_3(g)	-163.2	NH_3(g)	-46.2
CO(g)	-110.5	$N_2H_3CH_3$(l)	54
CO_2(g)	-393.5	NH_4Cl(s)	-315.4
HCl(g)	-92.3	NH_4ClO_4(s)	-295
HCN(g)	130.5	NO(g)	+90.4
HF(g)	-268.6	NO_2(g)	+33.9
HNO_3(aq)	-207.4	N_2O_4(l)	-20.
H_2O(g)	-241.8	$SnCl_4$(l)	-545.2
H_2O(l)	-285.8	SnO(s)	-286.2
H_3PO_4(l)	-1271.7	SnO_2(s)	-580.7
H_2S(g)	-20.1	SO_2(g)	-296.1
H_2SO_4(l)	-811.3	SO_3(g)	-395.2
$MgSO_4$(s)	-1278.2	ZnO(s)	-348.0
MnO(s)	-384.9	ZnS(s)	-202.9

1. Give the definition of the standard enthalpy of formation for a substance.

2. Write separate reactions for the formation of NaCl, $C_6H_{12}O_6$, and $PbSO_4$ that have ΔH° values equal to ΔH^o_f for each compound.

   a. NaCl: ____________________

   b. $C_6H_{12}O_6$: ____________________

   c. $PbSO_4$: ____________________

3. Determine the ΔH^o for each of these reactions. State whether each reaction is endothermic or exothermic.

   a. $2\ CO(g) + O_2(g) \rightarrow 2\ CO_2(g)$

   b. $NaOH(s) + HCl(g) \rightarrow NaCl(s) + H_2O(g)$

   c. $2\ H_2S(g) + 3\ O_2(g) \rightarrow 2\ H_2O(l) + 2\ SO_2(g)$

4. The standard enthalpy of combustion for xylene, $C_8H_{10}(l)$, is -3908 kJ mol^{-1}. Calculate the standard enthalpy of formation of $C_8H_{10}(l)$, in kJ mol^{-1}. *(Hint: Write chemical equations for combustion of Xylene.)*

Answers: 3) a: -566 kJ, b: -133.8 kJ, c: -1123.6 kJ 4) -669 kJ 5) a: -947.8 kJ, b: -292.2 kJ, c: -176.9 kJ 6) -2674.5 kJ 7) -4592 kJ 8) 162 kJ 9) 52.3 kJ 10) a: -904.4 kJ, b: -113.0 kJ, c: -140.3 kJ

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5. Use the values of ΔH^o_f in the reference table to calculate $\Delta H°$ for the following reactions:

   a. $2NH_3(g) + 3O_2(g) + 2CH_4(g) \rightarrow 2HCN(g) + 6H_2O(g)$

   b. $Ca_3(PO_4)_2(s) + 3H_2SO_4(l) \rightarrow 3CaSO_4(s) + 2H_3PO_4(l)$

   c. $NH_3(g) + HCl(g) \rightarrow NH_4Cl(s)$

6. The reusable booster rockets of the space shuttle use a mixture of aluminum and ammonium perchlorate as fuel. A possible reaction is: $3Al(s) + 3NH_4ClO_4(s) \rightarrow Al_2O_3(s) + AlCl_3(s) + 3NO(g) + 6H_2O(g)$. Calculate $\Delta H°$ for this reaction.

7. The space shuttle orbiter utilizes the oxidation of methyl hydrazine by dinitrogen tetroxide for propulsion: $5N_2O_4(l) + 4N_2H_3CH_3(l) \rightarrow 12H_2O(g) + 9N_2(g) + 4CO_2(g)$. Calculate $\Delta H°$ for this reaction.

8. Consider the reaction: $2ClF_3(g) + 2NH_3(g) \rightarrow N_2(g) + 6HF(g) + Cl_2(g)$; $\Delta H° = -1196$ kJ . Calculate ΔH^o_f for $ClF_3(g)$.

9. The enthalpy of combustion of ethane gas, $C_2H_4(g)$, is −1411.1 kJ/mol at 298 K. Calculate ΔH^o_f for $C_2H_4(g)$.

10. The Ostwald process for the commercial production of nitric acid from ammonia and oxygen involves the following steps. Use the values of ΔH^o_f in the reference table to calculate the value of $\Delta H°$ for each of the reactions.

   a. $4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g)$

   b. $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$

   c. $3NO_2(g) + H_2O(l) \rightarrow 2HNO_3(aq) + NO(g)$

Answers: 3) a: -566 kJ, b: -133.8 kJ, c: -1123.6 kJ 4) -669 kJ 5) a: -947.8 kJ, b: -292.2 kJ, c: -176.9 kJ 6) -2674.5 kJ 7) -4592 kJ 8) 162 kJ 9) 52.3 kJ
10) a: -904.4 kJ, b: -113.0 kJ, c: -140.3 kJ