 Hess' Law Name______________________

1. Oxidation of ClF by F_2 yields liquid ClF_3. Use the following thermochemical equations to apply Hess' Law and calculate ΔH^o_{rx} for the production of ClF_3.
   - $2ClF_{(g)} + O_{2(g)} \rightarrow Cl_2O_{(g)} + OF_{2(g)}$ $\Delta H^o = 167.5$ kJ
   - $2F_{2(g)} + O_{2(g)} \rightarrow 2OF_{2(g)}$ $\Delta H^o = -43.5$ kJ
   - $2ClF_{3(L)} + 2O_{2(g)} \rightarrow Cl_2O_{(g)} + 3OF_{2(g)}$ $\Delta H^o = 394.1$ kJ

2. Use the following information to find ΔH^o_f of gaseous HCl.
   - $N_{2(g)} + 3H_{2(g)} \rightarrow 2NH_{3(g)}$ $\Delta H^o_{rx} = -91.8$ kJ
   - $N_{2(g)} + 4H_{2(g)} + Cl_{2(g)} \rightarrow 2NH_4Cl_{(s)}$ $\Delta H^o_{rx} = -628.8$ kJ
   - $NH_{3(g)} + HCl_{(g)} \rightarrow NH_4Cl_{(s)}$ $\Delta H^o_{rx} = -176.2$ kJ

3. The chemistry of nitrogen oxides is very versatile. Given the following reactions and their standard enthalpy changes, calculate the heat of reaction for $N_2O_{3(g)} + N_2O_{5(s)} \rightarrow 2N_2O_{4(g)}$
   - $NO_{(g)} + NO_{2(g)} \rightarrow N_2O_{3(g)}$ $\Delta H^o_{rx} = -39.8$ kJ
   - $NO_{(g)} + NO_{2(g)} + O_{2(g)} \rightarrow N_2O_{5(g)}$ $\Delta H^o_{rx} = -112.5$ kJ
   - $2NO_{2(g)} \rightarrow N_2O_{4(g)}$ $\Delta H^o_{rx} = -57.2$ kJ
   - $2NO_{(g)} + O_{2(g)} \rightarrow 2NO_{2(g)}$ $\Delta H^o_{rx} = -114.2$ kJ
   - $N_2O_{5(s)} \rightarrow N_2O_{5(g)}$ $\Delta H^o_{subl} = +54.1$ kJ

Hess' Law

4. Given the following data:

   $S + {}^{3}/_{2}O_2 \rightarrow SO_3$ $\Delta H^o = -395$ kJ

   $2SO_2 + O_2 \rightarrow 2SO_3$ $\Delta H^o = -198$ kJ

   calculate ΔH^o for the reaction:

   $S + O_2 \rightarrow SO_2$

5. Given the following data:

   $2\ H_2 + O_2 \rightarrow 2\ H_2O$ $\Delta H^o = -484$ kJ

   $3\ O_2 \rightarrow 2O_3$ $\Delta H^o = 285$ kJ

   calculate ΔH^o for the reaction:

   $3\ H_2 + O_3 \rightarrow 3\ H_2O$

6. Given the following data:

   $H_2 + \frac{1}{2}O_2 \rightarrow H_2O$ $\Delta H^o = -286$ kJ

   $N_2O_5 + H_2O \rightarrow 2HNO_3$ $\Delta H^o = -77$ kJ

   $\frac{1}{2}N_2 + {}^{3}/_{2}O_2 + \frac{1}{2}\ H_2 \rightarrow HNO_3$ $\Delta H^o = -174$ kJ

   calculate ΔH^o for the reaction:

   $2N_2 + 5O_2 \rightarrow 2N_2O_5$

7. Given the following data:

   $C_2H_5 + {}^{5}/_{2}O_2 \rightarrow 2CO_2 + H_2O$ $\Delta H^o = -1300$ kJ

   $C + O_2 \rightarrow CO_2$ $\Delta H^o = -394$ kJ

   $H_2 + \frac{1}{2}O_2 \rightarrow H_2O$ $\Delta H^o = -286$ kJ

   calculate ΔH^o for the reaction:

   $2C + H_2 \rightarrow C_2H_5$

8. Given the following data:

   $2O_3 \rightarrow 3O_{2(g)}$ $\Delta H^o = -427$ kJ

   $O_2 \rightarrow 2O$ $\Delta H^o = 495$ kJ

   $NO + O_3 \rightarrow NO_2 + O_2$ $\Delta H^o = -199$ kJ

   calculate ΔH^o for the reaction:

   $NO + O \rightarrow NO_2$

9. The bombardier beetle uses an explosive discharge as a defensive measure. The chemical reaction involved is the oxidation of hydroquinone by hydrogen peroxide to produce quinone and water:

   $C_6H_4(OH)_2 + H_2O_2 \rightarrow C_6H_4O_2 + 2\ H_2O_{(L)}$

   Calculate ΔH^o for this reaction from the following data.

   $C_6H_4(OH)_2 \rightarrow C_6H_4O_2 + H_2$ $\Delta H^o = 177$ kJ

   $H_2O_{(g)} + \frac{1}{2}O_2 \rightarrow H_2O_2$ $\Delta H^o = 106$ kJ

   $H_2 + \frac{1}{2}\ O_2 \rightarrow H_2O_{(g)}$ $\Delta H^o = -242$ kJ

   $H_2O_{(g)} \rightarrow H_2O_{(L)}$ $\Delta H^o = -44$ kJ

10. Given the following data:

    $O_2 + H_2 \rightarrow 2OH$ $\Delta H^o = 78$ kJ

    $O_2 \rightarrow 2O$ $\Delta H^o = 495$ kJ

    $H_2 \rightarrow 2H$ $\Delta H^o = 436$ kJ

    calculate ΔH^o for the reaction:

    $O + H \rightarrow OH$

11. Calculate ΔH^o for this reaction

    $N_2H_4 + O_2 \rightarrow N_2 + 2\ H_2O$

    Given the following data.

    $2\ NH_3 + 3\ N_2O \rightarrow 4\ N_2 + 3\ H_2O$ $\Delta H^o = -1010$ kJ

    $N_2O + 3H_2 \rightarrow N_2H_4 + H_2O$ $\Delta H^o = -317$ kJ

    $2\ NH_3 + \frac{1}{2}\ O_2 \rightarrow N_2H_4 + H_2O$ $\Delta H^o = -143$ kJ

    $H_2 + \frac{1}{2}\ O_2 \rightarrow H_2O$ $\Delta H^o = -286$kJ

1. $\Delta H_{Rx} = -135.05$ kJ mol^{-1} of ClF_3
2. $\Delta H_{Rx} = -92.3$ kJ mol^{-1} of HCl
3. $\Delta H_{Rx} = -22.2$ kJ mol^{-1} of $N_2O_{3(g)}$ reacted
4. ΔH = −296 kJ

   choose the second reaction, reverse it and cut the stoich in half to get the single SO_2 on the right. Thus, you need to change the sign of the ΔH and cut the value in half

   $SO_3 \rightarrow SO_2 + \frac{1}{2}O_2$ $\Delta H^o = +99$ kJ

   choose the first reaction as is

   $S + \frac{3}{2}O_2 \rightarrow SO_3$ $\Delta H^o = -395$ kJ

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   $S + O_2 \rightarrow SO_2$ $\Delta H^o = -296$ kJ

5. ΔH = −869 kJ

   choose the first reaction, reverse it to get the O_3 on the left and divide by 3. Thus, you need to change the sign of the ⅓(ΔH)

   $\frac{2}{3} O_3 \rightarrow O_2$ $\Delta H^o = -95$ kJ

   add it to the second reaction as is

   $2 H_2 + O_2 \rightarrow 2 H_2O$ $\Delta H^o = -484$ kJ

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   $3/2 (2 H_2 + \frac{2}{3} O_3 \rightarrow 2 H_2O)$ $\Delta H^o = 3/2(-579)$ kJ

   $3 H_2 + O_3 \rightarrow 3 H_2O)$ $\Delta H^o = -869$ kJ

6. ΔH = +30 kJ

   choose the second reaction, reverse it and double the stoich to get the 2 N_2O_5 Thus, you need to change the sign and double the ΔH

   $4 HNO_3 \rightarrow 2 N_2O_5 + 2 H_2O$ $\Delta H^o = +154$ kJ

   choose the third reaction and quadruple it to eliminate the 4 HNO_3

   $2 N_2 + 6 O_2 + 2 H_2 \rightarrow 4 HNO_3$ $\Delta H^o = -696$ kJ

   choose the first reaction and reverse it and double it to eliminate the 2 H_2O

   $2 H_2O \rightarrow 2 H_2 + 1 O_2$ $\Delta H^o = +572$ kJ

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   $2N_2 + 5O_2 \rightarrow 2N_2O_5$ $\Delta H^o = +30$ kJ

7. ΔH = +226 kJ

   choose the first reaction, and reverse it to get the C_2H_5 on the right side. Thus, you need to change the sign of the ΔH

   $2 CO_2 + H_2O \rightarrow C_2H_5 + \frac{5}{2}O_2$ $\Delta H^o = +1300$ kJ

   choose the second reaction, double it and reverse it to eliminate the 2 CO_2

   $2 C + 2 O_2 \rightarrow 2 CO_2$ $\Delta H^o = -788$ kJ

   choose the third reaction as is to eliminate the H_2O

   $H_2 + \frac{1}{2}O_2 \rightarrow H_2O$ $\Delta H^o = -286$ kJ

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   $2C + H_2 \rightarrow C_2H_5$ $\Delta H^o = +226$ kJ

8. ΔH = −233 kJ

   choose the third reaction as is to get the NO_2 on the right side.

   $NO + O_3 \rightarrow NO_2 + O_2$ $\Delta H^o = -199$ kJ

   choose the second reaction, cut it in half it and reverse it to get the O on the left side.

   $O \rightarrow \frac{1}{2}O_2$ $\Delta H^o = -247.5$ kJ

   choose the third reaction, reverse it and cut divide the stoichiometry by 2, to leave a single O_3 to cancel

   $\frac{3}{2} O_2 \rightarrow O_3$ $\Delta H^o = +213.5$ kJ

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   $NO + O \rightarrow NO_2$ $\Delta H^o = -233$ kJ

9. ΔH = −259 kJ

   choose the first reaction as is

   $C_6H_4(OH)_2 \rightarrow C_6H_4O_2 + H_2$ $\Delta H^o = +]177$ kJ

   choose the second reaction and reverse it to get the H_2O_2 on the left.

   $H_2O_2 \rightarrow H_2O_{(g)} + \frac{1}{2} O_2$ $\Delta H^o = -106$ kJ

   choose the fourth reaction and double it to get 2 H_2O gas on the right side

   $2 H_2O_{(g)} \rightarrow 2 H_2O_{(L)}$ $\Delta H^o = -88$ kJ

   choose the third reaction as is double it to get one H_2 on the left side to cancel with the H_2 in the first reaction.

   $H_2 + \frac{1}{2} O_2 \rightarrow H_2O_{(g)}$ $\Delta H^o = -242$ kJ

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   $C_6H_4(OH)_2 + H_2O_2 \rightarrow C_6H_4O_2 + 2 H_2O_{(L)}$ $\Delta H^o = -259$ kJ

10. ΔH = −427 kJ

    cut the first reaction in half to get 1 OH on the right side.

    $\frac{1}{2} O_2 + \frac{1}{2} H_2 \rightarrow OH$ $\Delta H^o = +39$ kJ

    choose the second reaction, cut it in half it and reverse it to get the O on the left side.

    $O \rightarrow \frac{1}{2}O_2$ $\Delta H^o = -247.5$ kJ

    choose the third reaction, reverse it and cut divide the stoichiometry in half, to leave a single H on the left

    $H \rightarrow \frac{1}{2} H_2$ $\Delta H^o = -218$ kJ

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    $O + H \rightarrow OH$ $\Delta H^o = -427$ kJ

11. ΔH = −623 kJ

    this problem is a bit tricky and would involve lots of fractional stoichiometry unless you quadruple the final reaction − you wold find this out as you start off and realize that as you choose the first reaction you would need to divide it by 4 to get only 1 N_2 on the product side.

    $2 NH_3 + 3 N_2O \rightarrow 4 N_2 + 3 H_2O$ $\Delta H^o = -1010$ kJ

    Because N_2H_4 is in two different reactions, you can't use that molecule to help you know what to do, but the N2O in the first reaction must be removed so choose the second reaction and flip it and triple it to get the 3 N_2O on the correct side.

    $3 N_2H_4 + 3 H_2O \rightarrow 3 N_2O + 9 H_2$ $\Delta H^o = +951$ kJ

    since that gets 3 N_2H_4 on the left, you need the to flip the third reaction to get the extra N_2H_4 on the left side.

    $N_2H_4 + H_2O \rightarrow 2 NH_3 + \frac{1}{2} O_2$ $\Delta H^o = +143$ kJ

    the fourth reaction reaction can be tracked by seeing how many H2 are needed. The stoichiometry must be multiplied by 9 to eliminate the 9 H_2 from the second reaction above.

    $9 H_2 + 4.5 O_2 \rightarrow 9 H_2O$ $\Delta H^o = -2574$kJ

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    $4 N_2H_4 + 4 O_2 \rightarrow 4 N_2 + 8 H_2O$ $\Delta H^o = -2490$ kJ

    now cut the final reaction by 4 to get the correct stoichiometry and the ΔH should be divided by 4 as well to get the correct energy value.

    $N_2H_4 + O_2 \rightarrow N_2 + 2 H_2O$ $\Delta H^o = -623$ kJ