CHEMISTRY 11 AP – ENTHALPY CHANGES WORKSHEET

1) The complete decomposition of NOCl gas into its elements occurs by the following reaction:

$$2\,NOCl_{(g)} \rightarrow N_{2\,(g)} + O_{2\,(g)} + Cl_{2\,(g)}$$

Use the following two reactions and their enthalpy changes to determine the enthalpy change for the decomposition reaction.

$\frac{1}{2}N_{2\,(g)} + \frac{1}{2}O_{2\,(g)} \rightarrow NO_{(g)}$ flip x2	$\Delta H_f = +\,90.3$ kJ/mol x-2
$NO_{(g)} + \frac{1}{2}Cl_{2\,(g)} \rightarrow NOCl_{(g)}$ flip x2	$\Delta H_{rxn} = -\,38.6$ kJ/mol x-2

$2NO \rightarrow N_2 + O_2$ ΔH = −180.6 kJ/mol

$2NOCl \rightarrow 2NO + Cl_2$ ΔH = +77.2 kJ/mol

$2NOCl \rightarrow N_2 + O_2 + Cl_2$ ΔH = +103.4 kJ/mol

2) Polyvinyl chloride is commonly referred to as PVC. It is a polymer produced from a monomer formed by the addition of ethylene and chlorine gas. Use the following reactions and their enthalpy changes to determine the overall enthalpy change for the PVC monomer reaction:

$H_{2\,(g)} + Cl_{2\,(g)} \rightarrow 2\,HCl_{(g)}$	$\Delta H°_f = -\,184.6$ kJ/mol
$C_2H_{4\,(g)} + HCl_{(g)} \rightarrow C_2H_5Cl_{(l)}$	$\Delta H°_{rxn} = -\,65.0$ kJ/mol
$C_2H_3Cl_{(g)} + H_{2\,(g)} \rightarrow C_2H_5Cl_{(l)}$ flip	$\Delta H°_{rxn} = -\,138.9$ kJ/mol x-1
$C_2H_{4\,(g)} + Cl_{2\,(g)} \rightarrow C_2H_3Cl_{(l)} + HCl_{(g)}$	$\Delta H°_f = ?$

$H_2 + Cl_2 \rightarrow 2HCl$ ΔH = −184.6 kJ/mol

$C_2H_4 + HCl \rightarrow C_2H_5Cl$ ΔH = −65.0 kJ/mol

$C_2H_5Cl \rightarrow C_2H_3Cl + H_2$ ΔH = +138.9 kJ/mol

$C_2H_4 + Cl_2 \rightarrow C_2H_3Cl + HCl$ ΔH = −110.7 kJ/mol

3) Given the following data (all species are gases):

$2\,O_3 \rightarrow 3\,O_2$ flip ÷2	$\Delta H°_{diss} = -\,427$ kJ/mol ÷−2
$O_2 \rightarrow 2\,O$ flip ÷2	$\Delta H°_{diss} = +\,495$ kJ/mol ÷−2
$NO + O_3 \rightarrow NO_2 + O_2$	$\Delta H°_{rxn} = -\,199$ kJ/mol

Calculate the enthalpy change for the following reaction: $NO + O \rightarrow NO_2$

$1\frac{1}{2}O_2 \rightarrow O_3$ ΔH = +214 kJ/mol (+213.5 kJ/mol)

$O \rightarrow \frac{1}{2}O_2$ ΔH = −248 kJ/mol (−247.5 kJ/mol)

$NO + O_3 \rightarrow NO_2 + O_2$ ΔH = −199 kJ/mol

$NO + O \rightarrow NO_2$ ΔH = −233 kJ/mol

4) Determine the enthalpy change for the following reaction:

$$CH_{4\,(g)} + 4\,Cl_{2\,(g)} \rightarrow CCl_{4\,(l)} + 4\,HCl_{(g)}$$

Using the following information:

you may have doubled this rxn to origanally get the 4 Cl_2, but you would soon realize that this wasn't required

$C_{(s)} + 2\,H_{2\,(g)} \rightarrow CH_{4\,(g)}$ flip	$\Delta H°_f = -74.6$ kJ/mol	$\times -1$
$C_{(s)} + 2\,Cl_{2\,(g)} \rightarrow CCl_{4\,(g)}$	$\Delta H°_f = -95.7$ kJ/mol	
$H_{2\,(g)} + Cl_{2\,(g)} \rightarrow 2\,HCl_{(g)}$ $\times 2$	$\Delta H°_f = -92.3$ kJ/mol	$\times 2$

$CH_4 \rightarrow C + 2H_2$ $\quad \Delta H = +74.6$ kJ/mol

$C + 2\,Cl_2 \rightarrow CCl_4$ $\quad \Delta H = -95.7$ kJ/mol

$2H_2 + 2\,Cl_2 \rightarrow 4\,HCl$ $\quad \Delta H = -185$ kJ/mol (-184.6 kJ/mol)

$CH_4 + 4Cl_2 \rightarrow CCl_4 + 4HCl$ $\quad \Delta H = -206$ kJ/mol

5) Use the values for Heats of Formation on Page 30 of your notes to determine the enthalpy change for each of the following reactions:

(a) $2\,H_2S_{(g)} + 3\,O_{2\,(g)} \rightarrow 2\,SO_{2\,(g)} + 2\,H_2O_{(l)}$

$$\Delta H = [(2)(\Delta H°_f\,SO_2) + (2)(\Delta H°_f\,H_2O)] - [(2)(\Delta H°_f\,H_2S) + (3)(\Delta H°_f\,O_2)]$$

$$= [(2)(-296.8\text{ kJ}) + (2)(-285.8\text{ kJ})] - [(2)(-20.2\text{ kJ}) + (3)(0\text{ kJ})]$$

$$= (-1165.2\text{ kJ}) - (-40.4\text{ kJ})$$

$$= -1124.8\text{ kJ}$$

(b) The Ostwald process for making nitric acid involves multiple steps, beginning with ammonia reacting with oxygen, forming nitrogen monoxide and water.

$$4\,NH_3 + 5\,O_2 \rightarrow 4\,NO + 6\,H_2O$$

$$\Delta H = [(4)(\Delta H°_f\,NO) + (6)(\Delta H°_f\,H_2O)] - [(4)(\Delta H°_f\,NH_3) + (5)(\Delta H°_f\,O_2)]$$

$$= [(4)(+90.3\text{ kJ}) + (6)(-241.8\text{ kJ})] - [(4)(-45.9\text{ kJ}) + (5)(0\text{ kJ})]$$

$$= (-1089.6\text{ kJ}) - (-183.6\text{ kJ})$$

$$= -906\text{ kJ}$$

(c) 

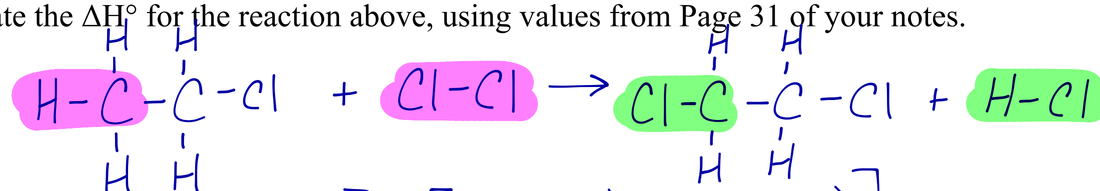
$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$

$$\Delta H = [(1)(\Delta H_f^\circ CO_2) + (2)(\Delta H_f^\circ H_2O)] - [(1)(\Delta H_f^\circ CH_4) + (2)(\Delta H_f^\circ O_2)]$$
$$= [(1)(-393.5\,kJ) + (2)(-285.8\,kJ)] - [(1)(-74.9\,kJ) + (2)(0\,kJ)]$$
$$= (-965.1\,kJ) - (-74.9\,kJ)$$
$$= -890.2\,kJ$$

6) Chlorine gas can react in a substitution reaction with the gaseous monomer mentioned in question 2 as follows:

$$C_2H_5Cl_{(g)} + Cl_{2\,(g)} \rightarrow C_2H_4Cl_{2\,(g)} + HCl_{(g)}$$

(a) Calculate the ΔH° for the reaction above, using values from Page 31 of your notes.



$$\Delta H = [(1)(C{-}H) + (1)(Cl{-}Cl)] - [(1)(C{-}Cl) + (1)(H{-}Cl)]$$
$$= [(1)(413\,kJ) + (1)(243\,kJ)] - [(1)(339\,kJ) + (1)(427\,kJ)]$$
$$= (656\,kJ) - (766\,kJ)$$
$$= -110\,kJ = -1.10 \times 10^2\,kJ$$

(b) Repeat the calculation done in part (a) using ΔH°$_f$ values from Page 30 of your notes.

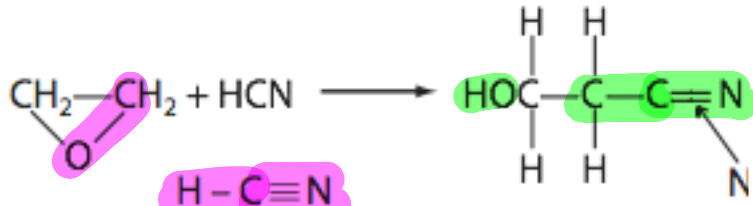
$$\Delta H = [(1)(\Delta H_f^\circ C_2H_4Cl_2) + (1)(\Delta H_f^\circ HCl)] - [(1)(\Delta H_f^\circ C_2H_5Cl) + (1)(\Delta H_f^\circ Cl_2)]$$
$$= [(1)(-166.8\,kJ) + (1)(-92.3\,kJ)] - [(1)(-112.2\,kJ) + (1)(0\,kJ)]$$
$$= (-259.1\,kJ) - (-112.2\,kJ)$$
$$= -146.9\,kJ$$

(c) Compare the answer to part (a) with part (b). Comment on the comparison.

Since bond energies are averages, the answer to enthalpy problems using bond energies might not be exactly the same as the one to calculate using heats of formation as in this example.

7) Use a highlighter or some other method to indicate the bonds that break on the reactant side and form on the product side of this reaction. If a bond remains intact there is no need to break and reform it. Calculate the enthalpy change using the bond energy values on Page 31 of your notes.

(a)



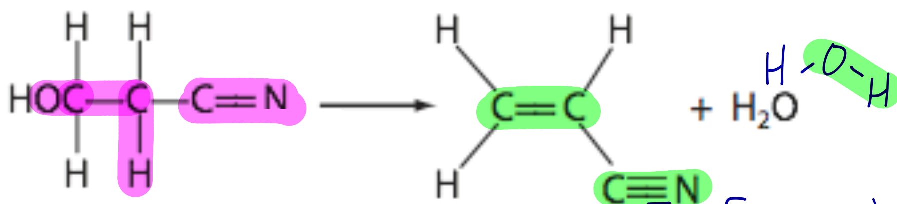
$$\Delta H_f = [(1)(C-O) + (1)(C-H) + (1)(C\equiv N)] - [(1)(O-H) + (1)(C-C) + (1)(C=N)]$$

$$= [(1)(358\,kJ) + (1)(413\,kJ) + (1)(891\,kJ)] - [(1)(467\,kJ) + (1)(347\,kJ) + (1)(615\,kJ)]$$

$$= (1662\,kJ) - (1429\,kJ)$$

$$= 233\,kJ/mol\ rxn$$

(b)



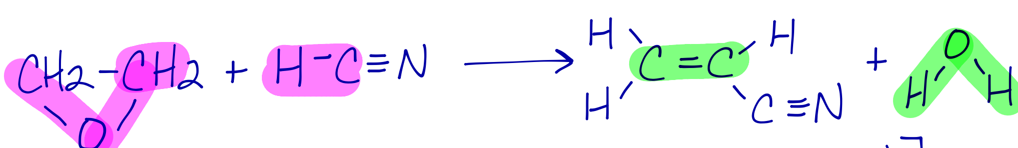
$$\Delta H = [(1)(C-O) + (1)(C-C) + (1)(C-H) + (1)(C=N)] - [(1)(C=C) + (1)(C\equiv N) + (1)(O-H)]$$

$$= [(1)(358\,kJ) + (1)(347\,kJ) + (1)(413\,kJ) + (1)(615\,kJ)] - [(1)(614\,kJ) + (1)(891\,kJ) + (1)(467\,kJ)]$$

$$= (1733\,kJ) - (1972\,kJ)$$

$$= -239\ kJ/mol\ rxn$$

(c) Combine (a) and (b) into one reaction and calculate the overall enthalpy change.



$$\Delta H = [(2)(C-O) + (2)(C-H)] - [(1)(C=C) + (2)(O-H)]$$

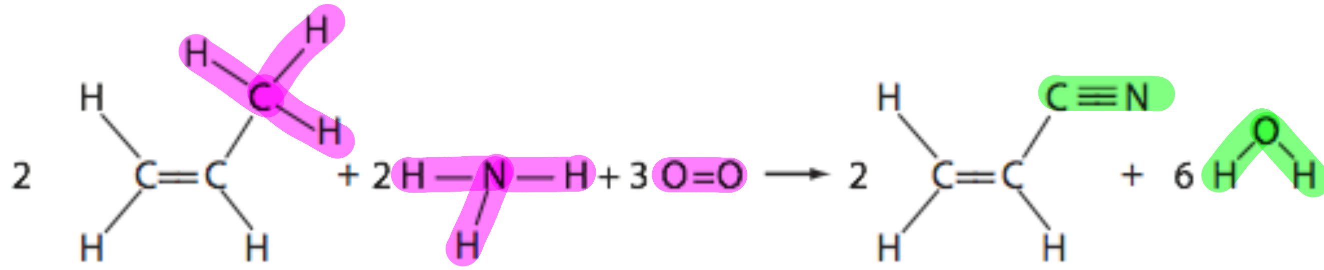
$$= [(2)(358\,kJ) + (2)(413\,kJ)] - [(1)(614\,kJ) + (2)(467\,kJ)]$$

$$= (1542\,kJ) - (1548\,kJ)$$

$$= -6\ kJ/mol\ rxn$$

8) The following shows the structural formulas for the reaction:

$$2\ CH_2CHCH_{3\ (g)} + 2\ NH_{3\ (g)} + 3\ O_{2\ (g)} \rightarrow 2\ CH_2CHCN_{\ (g)} + 6\ H_2O_{\ (g)}$$



Use the bond energy on Page 31 of your notes to calculate $\Delta H°_{rxn}$ for the given reaction.

$\Delta H = [(6)(C\text{-}H) + (6)(N\text{-}H) + (3)(O{=}O)] - [(2)(C{\equiv}N) + (12)(O\text{-}H)]$

$= [(6)(413\ kJ) + (6)(391\ kJ) + (3)(498\ kJ)] - [(2)(891\ kJ) + (12)(467\ kJ)]$

$= (6318\ kJ) - (7386\ kJ)$

$= -1068\ kJ/mol\ rxn$