Multistep Calculations

1. Sulphuric acid reacts with limestone, calcium carbonate, in the following reaction:

$$CaCO_{3\,(s)} + H_2SO_{4\,(l)} \rightarrow CaSO_{4\,(s)} + H_2O_{(l)} + CO_{2\,(g)}$$

(i) Using the information in Appendix C6 (pg 799) in you text, determine the enthalpy change for reaction above.
(ii) Determine the enthalpy change that occurs if 156.9 g of calcium carbonate reacts with excess sulphuric acid.
(iii) Determine the temperature change that would occur on 556.9 mL of water.

(i)

	$CaCO_{3\,(s)}$	+	$H_2SO_{4\,(l)}$	→	$CaSO_{4\,(s)}$	+	$H_2O_{(l)}$	+	$CO_{2\,(g)}$
ΔH^o_f (kJ/mol)	-1206.9		-814.0		-1434.1		-285.8		-393.5

$\Delta H = \sum n\Delta H^o_{f\ products} - \sum n\Delta H^o_{f\ reactants}$

$= [(1\ mol\ CaSO_4)(-1431.1\ kJ/mol\ CaSO_4) + (1mol\ H_2O)(-285.5\ kJ/mol\ H_2O) + (1\ mol\ CO_2)(-393.5\ kJ/mol\ CO_2)] -$
$[(1\ mol\ CaCO_3)(-1206.9\ kJ/mol\ CaCO_3) + (1\ mol\ H_2SO_4)(-814\ kJ/mol\ H_2SO_4)$

$\Delta H = -92.5$ kJ

(ii)

<u>system – $CaCO_3$</u>
m = 156.9 g
M = 100.09 g/mol

Since eq'n is balanced based on 1 mol $CaCO_3$
$\Delta H_{neutr} = -92.5$ kJ / mol $CaCO_3$

$\Delta H = n\ \Delta H_{neut}$
$= (m/M)\ \Delta H_{neut}$
$= (156.9\ g) / (100.09\ g/mol\ CaCO_3)(-92.5\ kJ / mol\ CaCO_3)$
$= -144.9$ kJ

$\Delta H = -144.9$ kJ

(iii)

<u>surrounding – H_2O</u>
V = 556.9 mL
m = 0.5569 kG
c = 4.184 kJ / kg ^oC
ΔT =

$\Delta H = -q = -mc\Delta T$

$-144.9\ kJ = (0.5569\ kg)(4.184\ kJ/kg\ ^oC)\ \Delta T$

$\Delta T = 62.2^oC$

exothermic, therefore $\Delta H = -q$

2. The combustion of 0.2500 g of phosphorus trichloride, produces $POCl_3$, results in the temperature of 100.0 mL of water to rise 3.44°C. Using this information and information in Appendix C6, determine the molar enthalpy of formation for $POCl_3$.

$PCl_{3\,(l)} + ½\ O_2 \rightarrow POCl_{3\,(g)}$

<u>System – $POCl_3$</u>
m = 0.250 g
M = 137.32 g/mol PCl_3
ΔH_{comb} = kJ/mol PCl_3

<u>Surrounding – H_2O</u>
m = 100.0 g = 0.1000 kg
c = 4.184 kJ / kg °C
$\Delta T = 3.44°C$

exothermic, therefore $\Delta H = - q$

$q = mc\Delta T = (0.100\ kg)(4.184\ kJ / kg\ °C)(3.44°C) = 1.44\ kJ$

$(\Delta H_{comb})n = \Delta H = - q$

$(\Delta H_{comb}) = - 1.44\ kJ)(137.32\ g/mol) / (0.250\ g)$
$= -790.6\ kJ/mol$

Since BCE is based on 1 mole of PCl_3 $\Delta H = (\Delta H_{comb})n = (-790.6\ kJ/mol\ PCl_3)(1\ mol\ PCl_3) = -790.6\ kJ$

	$PCl_{3\,(l)}$	+	$O_{2\,(g)}$	→	$POCl_{3\,(g)}$
$\Delta H°_f$ (kJ/mol)	-319.7		0		x

$\Delta H = \sum \Delta H°_{f\ prod} - \sum \Delta H°_{f\ react} = [(1mol\ POCl_3)(x\ kJ/mol\ POCl_3)]$
$- [(1\ mol\ PCl_3)(-319.7\ kJ/mol\ PCl_3) + (½\ mol\ O_2)(0\ kJ/mol\ O_2)] = - 790.6\ kJ$

$\Delta H°_f = -110.3\ jK / mol\ POCl_3$

3. Dinitrogen tetraoxide forms natural through the synthesis reaction of two nitrogen dioxide molecules according to the equation below:

$$2\ NO_{2\ (g)} \rightarrow N_2O_{4\ (g)}$$

The above reactions was determined to have a molar enthalpy of ΔH_{rxn} = - 57.20 kJ/mol NO_2. Using this information determine:

(i) The standard enthalpy of formation for dinitrogen tetraoxide.

(ii) How many grams of nitrogen dioxide has to undergo the above conversion in order to raise the temperature of 50.7 mL of water from 56.7°C to 112°C.

$$2\ NO_{2\ (g)} \rightarrow N_2O_{4\ (g)}$$

$\Delta H = (\Delta H_{comb})n = (2\ mol\ NO_2)(-57.2\ kJ/mol\ NO_2) = -\ 114.4\ kJ$

	$2\ NO_{2\ (g)}$	$\rightarrow$	$N_2O_{4\ (g)}$
ΔH^o_f	33.2		x

$\Delta H = \sum \Delta H^o_{f\ prod} - \sum \Delta H^o_{f\ react} = [(1\ mol\ N_2O_4)(x\ kJ/mpl\ N_2O_4)] - [(2\ mol\ NO_2)(33.2\ kJ/mol\ NO_2)] = -\ 114.4\ kJ$

$\Delta H^o_f = 180.8\ kJ / mol\ N_2O_4$

<u>System – NO_2</u>

m = g

M = 46.01 g/mol

ΔH_{rxn} = -57.20 kJ/mol NO_2

exothermic, therefore $\Delta H = -q$

$(\Delta H_{comb})n = \Delta H = -\ q$

$(-57.20\ kJ/mol\ NO_2)\ (m / 46.01\ g/mol\ NO_2) = -\ 125.20\ kJ$

m = 100.70 g

<u>Surrounding – H_2O</u>

m = 50.7 g = 0.0507 kg

c_{liquid} = 4.184 kJ/kg °C

c_{steam} = 2.01 kJ/kg °C

ΔT = 56.7 to 120°C

this temp change includes a change of state, therefore

$q = q_1 + q_2 + q_3$

$= mc\Delta T + nh_{vap} + mc\Delta T$

$= (0.0507\ kg)(4.184\ kJ/kg^oC)(43.3^oC) +$

$(50.7\ g)/(18.02\ g/mol\ H_2O)(40.8\ kJ/mol\ H_2O) +$

$(0.0507\ kg)(2.01\ kJ/kg^oC)(20.0^oC)$

q = 125.20 kJ