

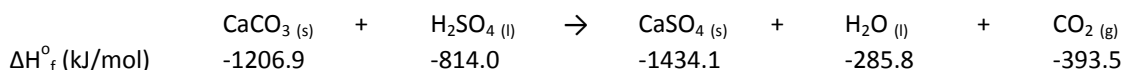
Multistep Calculations

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



- (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)



$$\Delta H = \sum n \Delta H_f^\circ \text{ products} - \sum n \Delta H_f^\circ \text{ reactants}$$

$$= [(1 \text{ mol CaSO}_4)(-1431.1 \text{ kJ/mol CaSO}_4) + (1 \text{ mol H}_2\text{O})(-285.5 \text{ kJ/mol H}_2\text{O}) + (1 \text{ mol CO}_2)(-393.5 \text{ kJ/mol CO}_2)] - [(1 \text{ mol CaCO}_3)(-1206.9 \text{ kJ/mol CaCO}_3) + (1 \text{ mol H}_2\text{SO}_4)(-814 \text{ kJ/mol H}_2\text{SO}_4)]$$

$$\Delta H = -92.5 \text{ kJ}$$

(ii)

system – CaCO₃

$$m = 156.9 \text{ g}$$

$$M = 100.09 \text{ g/mol}$$

Since eq'n is balanced based on 1 mol CaCO₃

$$\Delta H_{\text{neutr}} = -92.5 \text{ kJ / mol CaCO}_3$$

$$\Delta H = n \Delta H_{\text{neut}}$$

$$= (m/M) \Delta H_{\text{neut}}$$

$$= (156.9 \text{ g}) / (100.09 \text{ g/mol CaCO}_3)(-92.5 \text{ kJ / mol CaCO}_3)$$

$$= -144.9 \text{ kJ}$$

$$\Delta H = -144.9 \text{ kJ}$$

(iii)

surrounding – H₂O

$$V = 556.9 \text{ mL}$$

$$m = 0.5569 \text{ kg}$$

$$c = 4.184 \text{ kJ / kg } ^\circ\text{C}$$

$$\Delta T =$$

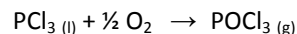
$$\Delta H = -q = -mc\Delta T$$

$$-144.9 \text{ kJ} = (0.5569 \text{ kg})(4.184 \text{ kJ/kg } ^\circ\text{C}) \Delta T$$

$$\Delta T = 62.2^\circ\text{C}$$

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 .



System – POCl_3

$$m = 0.250 \text{ g}$$

$$M = 137.32 \text{ g/mol PCl}_3$$

$$\Delta H_{\text{comb}} = \quad \text{kJ/mol PCl}_3$$

Surrounding – H_2O

$$m = 100.0 \text{ g} = 0.1000 \text{ kg}$$

$$c = 4.184 \text{ kJ / kg } ^\circ\text{C}$$

$$\Delta T = 3.44^\circ\text{C}$$

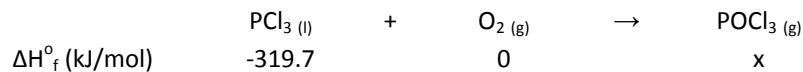
exothermic, therefore $\Delta H = -q$

$$q = mc\Delta T = (0.100 \text{ kg})(4.184 \text{ kJ / kg } ^\circ\text{C})(3.44^\circ\text{C}) = 1.44 \text{ kJ}$$

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

$$\begin{aligned} (\Delta H_{\text{comb}}) &= (-1.44 \text{ kJ})(137.32 \text{ g/mol}) / (0.250 \text{ g}) \\ &= -790.6 \text{ kJ/mol} \end{aligned}$$

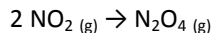
Since BCE is based on 1 mole of PCl_3 $\Delta H = (\Delta H_{\text{comb}})n = (-790.6 \text{ kJ/mol PCl}_3)(1 \text{ mol PCl}_3) = -790.6 \text{ kJ}$



$$\begin{aligned} \Delta H &= \sum \Delta H_f^\circ \text{ prod} - \sum \Delta H_f^\circ \text{ react} = [(1 \text{ mol POCl}_3)(x \text{ kJ/mol POCl}_3)] \\ &\quad - [(1 \text{ mol PCl}_3)(-319.7 \text{ kJ/mol PCl}_3) + (\frac{1}{2} \text{ mol O}_2)(0 \text{ kJ/mol O}_2)] = -790.6 \text{ kJ} \end{aligned}$$

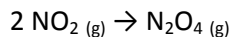
$$\Delta H_f^\circ = -110.3 \text{ kJ / mol POCl}_3$$

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

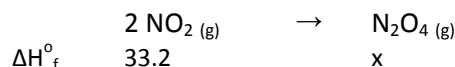


The above reaction was determined to have a molar enthalpy of $\Delta H_{\text{rxn}} = -57.20 \text{ kJ/mol NO}_2$. Using this information determine:

- (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 .



$$\Delta H = (\Delta H_{\text{comb}})n = (2 \text{ mol NO}_2)(-57.2 \text{ kJ/mol NO}_2) = -114.4 \text{ kJ}$$



$$\Delta H = \sum \Delta H_f^\circ \text{ prod} - \sum \Delta H_f^\circ \text{ react} = [(1 \text{ mol N}_2\text{O}_4)(x \text{ kJ/mol N}_2\text{O}_4)] - [(2 \text{ mol NO}_2)(33.2 \text{ kJ/mol NO}_2)] = -114.4 \text{ kJ}$$

$$\Delta H_f^\circ = 180.8 \text{ kJ/mol N}_2\text{O}_4$$

System – NO₂

$$m = \quad \text{g}$$

$$M = 46.01 \text{ g/mol}$$

$$\Delta H_{\text{rxn}} = -57.20 \text{ kJ/mol NO}_2$$

exothermic, therefore $\Delta H = -q$

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

$$(-57.20 \text{ kJ/mol NO}_2) (m / 46.01 \text{ g/mol NO}_2) = -125.20 \text{ kJ}$$

$$m = 100.70 \text{ g}$$

Surrounding – H₂O

$$m = 50.7 \text{ g} = 0.0507 \text{ kg}$$

$$c_{\text{liquid}} = 4.184 \text{ kJ/kg}^\circ\text{C}$$

$$c_{\text{steam}} = 2.01 \text{ kJ/kg}^\circ\text{C}$$

$$\Delta T = 56.7 \text{ to } 120^\circ\text{C}$$

this temp change includes a change of state, therefore

$$q = q_1 + q_2 + q_3$$

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

$$= (0.0507 \text{ kg})(4.184 \text{ kJ/kg}^\circ\text{C})(43.3^\circ\text{C}) +$$

$$(50.7 \text{ g}) / (18.02 \text{ g/mol H}_2\text{O})(40.8 \text{ kJ/mol H}_2\text{O}) +$$

$$(0.0507 \text{ kg})(2.01 \text{ kJ/kg}^\circ\text{C})(20.0^\circ\text{C})$$

$$q = 125.20 \text{ kJ}$$