5.2 Hess's Law

1. Using the equations below:

   $C(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta H = -390$ kJ

   $Mn(s) + O_2(g) \rightarrow MnO_2(s)$ $\Delta H = +520$ kJ

   What is ΔH (in kJ) for the following reaction? $MnO_2(s) + C(s) \rightarrow Mn(s) + CO_2(g)$

   a. 910
   b. 130
   c. −130
   d. −910

2. Using the equations below

   $Cu(s) + \frac{1}{2}O_2(g) \rightarrow CuO(s)$ $\Delta H^\ominus = +156$ kJ

   $2Cu(s) + \frac{1}{2}O_2(g) \rightarrow Cu_2O(s)$ $\Delta H^\ominus = -170$ kJ

   What is the value of $\Delta H^\ominus$ (in kJ) for the following reaction? $2CuO(s) \rightarrow Cu_2O(s) + \frac{1}{2}O_2(g)$

   a. 142
   b. 15
   c. −15
   d. −142

3. Calculate the standard enthalpy change ΔH^θ for the reaction:

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

   Using the information below:

   $N_2(g) + O_2(g) \rightarrow 2NO(g)$ $\Delta H^\theta = +180.5$ kJ

   $N_2(g) + 2O_2(g) \rightarrow 2NO_2(g)$ $\Delta H^\theta = +66.4$ kJ

4. Calculate the standard enthalpy change ΔH^θ for the reaction:

   $C_2H_4(g) + 3O_2(g) \rightarrow 2CO_2(g) + 2H2O(l)$

   Using the information below:

   $2C_2H_5OH(l) \rightarrow 2C_2H_4(g) + 2H_2O(l)$ $\Delta H^\theta = -86$ kJ

   $2CO_2(g) + 3H_2O(l) \rightarrow C_2H_5OH(l) + 3O_2(g)$ $\Delta H^\theta = +1386$ kJ

5. Calculate the standard enthalpy change ΔH^θ for the reaction:

$2C(graphite) + 2H_2(g) \rightarrow C_2H_4(g)$

Using the information below:

$2C(graphite) + 2O_2(g) \rightarrow 2CO_2(g)$ $\Delta H^\theta = -790$ kJ

$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$ $\Delta H^\theta = -574$ kJ

$2CO_2(g) + 2H_2O(l) \rightarrow C_2H_4(g) + 3O_2$ $\Delta H^\theta = +1416$ kJ

$2C + 2O_2 \rightarrow 2CO_2$ -790

$2H_2 + O_2 \rightarrow 2H_2O$ -574

$2CO_2 + 2H_2O \rightarrow C_2H_4 + 3O_2$ $+1416$

52 kJ

6. Calculate the standard enthalpy change ΔH^θ for the reaction:

$C(graphite) + \frac{1}{2} O_2(g) \rightarrow CO(g)$

Using the information below:

$C(graphite) + O_2(g) \rightarrow CO_2(g)$ $\Delta H^\theta = -394$ kJ

$CO(g) + \frac{1}{2} O_2(g) \rightarrow CO_2(g)$ $\Delta H^\theta = -283$ kJ

$C + \frac{1}{2}O_2 \rightarrow CO_2$ -394

$CO_2 \rightarrow CO + \frac{1}{2}O_2$ $+ -283$

-687 kJ

7. What is ΔH for the reaction below in kJ? $CS_2(g) + 3O_2(g) \rightarrow CO_2(g) + 2SO_2(g)$

[ΔH_f / kJ mol^{-1}: $CS_2(g)$ 110, $CO_2(g)$ – 390, $SO_2(g)$ – 290]

a. −570
b. −790
c. −860
d. −1080

$\Delta H_f^\ominus = \Sigma \Delta H_p - \Sigma \Delta H_r$

$= (-390 + 2(-290)) - (+110)$

$= -970 - 110$

8. The standard enthalpy change of formation of $Al_2O_3(s)$ is −1669 kJ mol^{-1} and the standard enthalpy change of formation of $Fe_2O_3(s)$ is −822 kJ mol^{-1}.

(i) Use these values to calculate $\Delta H^\ominus$ for the following reaction.

$Fe_2O_3(s) + 2Al(s) \rightarrow 2Fe(s) + Al_2O_3(s)$

$-822 \quad 0 \quad 0 \quad -1669$

0 → elements pure form

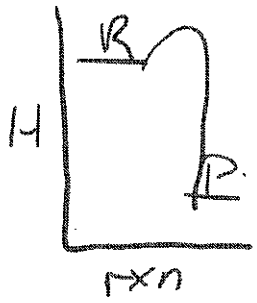
State whether the reaction is exothermic or endothermic.

$\Delta H^\ominus_{rxn} = \Sigma \Delta H_p - \Sigma \Delta H_f$

$= (-1669) - (-822)$

$= -847$ kJ mol^{-1} exothermic

(ii) Draw an enthalpy level diagram to represent this reaction. State the conditions under which standard enthalpy changes are measured.



T = 298K
P = 100 kPa

9. Define the term *standard enthalpy of formation*, and write the equation for the standard enthalpy of formation of ethanol.

ΔH associated with formation of 1 mol of substance from elements in their standard state under standard conditions.

$2C_{(graphite)} + 3H_{2(g)} + \frac{1}{2}O_{2(g)} \rightarrow C_2H_5OH_{(l)}$

10. Which of the following does not have a standard heat of formation of zero at 25°C and 1.00×10^5 Pa?
    a. $Cl_2(g)$ - correct state
    b. $I_2(s)$ - correct state
    c. **$Br_2(g)$** - liquid
    d. $Na(s)$ - correct state

11. Which of the following does have a standard heat of formation value of zero at 25°C and 1.00×10^5 Pa?
    a. $H(g) \rightarrow H_{2(g)}$
    b. $Hg(s) \rightarrow Hg_{(l)}$
    c. C(diamond) → C(graphite)
    d. **Si(s)** - correct

12. Write the thermochemical equation for the standard enthalpy of formation of propanone CH_3COCH_3.

$3C_{(graphite)} + 3H_{2(g)} + \frac{1}{2}O_{2(g)} \rightarrow C_3H_6O \quad \Delta H_f^\circ = -248$ kJ mol^{-1}

13. Calculate ΔH^θ (in kJ mol^{-1}) for the reaction: $Fe_3O_4(s) + 2C(graphite) \rightarrow 3Fe(s) + 2CO_2(g)$
    $-1118 \quad 0 \quad 0 \quad 2(-394)$

Substance: $Fe_3O_4(s)$; Heat of Formation: -1118 kJ mol^{-1}
Substance: $CO_2(g)$; Heat of Formation = - 394 kJ mol^{-1}

$\Delta H^\theta_{rxn} = \Sigma \Delta H_p - \Sigma \Delta H_r$
$= 2(-394) - (-1118)$
$= +330$ kJ mol^{-1}

14. Enthalpy changes of combustion data are tabulated in section 13 of the IB Data Booklet.

a. Give a chemical equation for the formation of benzene (thermochemical equation).

$6\,C_{(graphite)} + 3\,H_{2(g)} \rightarrow 1\,C_6H_{6(l)}$

b. Calculate ΔH^{θ}_f for benzene in the following reaction. Use the data in section 13 to calculate the enthalpy of formation for benzene. (section 13 gives the values for the ΔH^{θ}_{rxn}.

$C_6H_6(l) + 7\,½\,O_2(g) \rightarrow 6CO_2(g) + 3H_2O(g)$

$-3268 \quad 0 \quad 6(-394) \quad 3(-286)$

$\Delta H^{\theta}_{rxn} = [6(-394) + 3(-286)] - (-3268)$

$= +48\ kJ\,mol^{-1}$