Hess's Law Worksheet - answers

1. Calculate ΔH for the reaction: $C_2H_{4\,(g)} + H_{2\,(g)} \rightarrow C_2H_{6\,(g)}$, from the following data.

$C_2H_{4\,(g)} + 3\ O_{2\,(g)} \rightarrow 2\ CO_2\ (g) + 2\ H_2O_{\,(l)}$ ΔH = -1411. kJ

$C_2H_{6\,(g)} + 3½\ O_{2\,(g)} \rightarrow 2\ CO_2\ (g) + 3\ H_2O_{\,(l)}$ ΔH = -1560. kJ

$H_{2\,(g)} + ½\ O_{2\,(g)} \rightarrow H_2O_{\,(l)}$ ΔH = -285.8 kJ

$C_2H_{4\,(g)} + 3\ O_{2\,(g)}$	→	$2\ CO_2\ (g) + 2\ H_2O_{\,(l)}$	ΔH_1	X 1
$C_2H_{6\,(g)} + 3½\ O_{2\,(g)}$	→	$2\ CO_2\ (g) + 3\ H_2O_{\,(l)}$	ΔH_2	X -1
$H_{2\,(g)} + ½\ O_{2\,(g)}$	→	$H_2O_{\,(l)}$	ΔH_3	X 1

$C_2H_{4\,(g)} + 3\ O_{2\,(g)}$	→	$2\ CO_2\ (g) + 2\ H_2O_{\,(l)}$	ΔH_1
$2\ CO_2\ (g) + 3\ H_2O_{\,(l)}$	→	$C_2H_{6\,(g)} + 3½\ O_{2\,(g)}$	$-\Delta H_2$
$H_{2\,(g)} + ½\ O_{2\,(g)}$	→	$H_2O_{\,(l)}$	ΔH_3

$C_2H_{4\,(g)} + H_{2\,(g)} \rightarrow C_2H_{6\,(g)}$

$\Delta H = \Delta H_1 - \Delta H_2 + \Delta H_3 = -1411 + 1560 - 285.8 =$ **- 126.8 kJ**

2. Calculate ΔH for the reaction $4\ NH_{3\,(g)} + 5\ O_{2\,(g)} \rightarrow 4\ NO_{\,(g)} + 6\ H_2O_{\,(g)}$, from the following data.

$N_{2\,(g)} + O_{2\,(g)} \rightarrow 2\ NO_{\,(g)}$ ΔH = -180.5 kJ

$N_{2\,(g)} + 3\ H_{2\,(g)} \rightarrow 2\ NH_{3\,(g)}$ ΔH = -91.8 kJ

$2\ H_{2\,(g)} + O_{2\,(g)} \rightarrow 2\ H_2O_{\,(g)}$ ΔH = -483.6 kJ

$N_{2\,(g)} + O_{2\,(g)}$	→	$2\ NO_{\,(g)}$	ΔH_1	X 2
$N_{2\,(g)} + 3\ H_{2\,(g)}$	→	$2\ NH_{3\,(g)}$	ΔH_2	X -2
$2\ H_{2\,(g)} + O_{2\,(g)}$	→	$2\ H_2O_{\,(g)}$	ΔH_3	X 3

$2\ N_{2\,(g)} + 2\ O_{2\,(g)}$	→	$4\ NO_{\,(g)}$	$2\ \Delta H_1$
$4\ NH_{3\,(g)}$	→	$2\ N_{2\,(g)} + 6\ H_{2\,(g)}$	$-2\ \Delta H_2$
$6\ H_{2\,(g)} + 3\ O_{2\,(g)}$	→	$6\ H_2O_{\,(g)}$	$3\ \Delta H_3$

$4\ NH_{3\,(g)} + 5\ O_{2\,(g)} \rightarrow 4\ NO_{\,(g)} + 6\ H_2O_{\,(g)}$

$\Delta H = 2\Delta H_1 - 2\Delta H_2 + 3\Delta H_3 = 2(-180.5) - 2(-91.8) + 3(-483.6) =$ **- 1628.2 kJ**

3. Find ΔH for the reaction $3H_{2\,(g)} + 2C_{\,(s)} + ½\ O_{2\,(g)} \longrightarrow C_2H_5OH_{\,(l)}$, using the following thermochemical data.

$C_2H_5OH_{\,(l)} + 3\ O_{2\,(g)} \longrightarrow 2\ CO_{2\,(g)} + 3\ H_2O_{\,(l)}$ ΔH = -875. kJ

$C_{\,(s)} + O_{2\,(g)} \longrightarrow CO_{2\,(g)}$ ΔH = -394.51 kJ

$H_{2\,(g)} + ½\ O_{2\,(g)} \longrightarrow H_2O_{\,(l)}$ ΔH = -285.8 kJ

$C_2H_5OH_{\,(l)} + 3\ O_{2\,(g)}$	→	$2\ CO_{2\,(g)} + 3\ H_2O_{\,(l)}$	ΔH_1	x -1
$C_{\,(s)} + O_{2\,(g)}$	→	$CO_{2\,(g)}$	ΔH_2	x 2
$H_{2\,(g)} + ½\ O_{2\,(g)}$	→	$H_2O_{\,(l)}$	ΔH_3	x 3
~~$2\ CO_{2\,(g)} + 3\ H_2O_{\,(l)}$~~	→	$C_2H_5OH_{\,(l)} + 3\ O_{2\,(g)}$	$-\Delta H_1$	
$2\ C_{\,(s)} + 2\ O_{2\,(g)}$	→	~~$2\ CO_{2\,(g)}$~~	$2\ \Delta H_2$	
$3\ H_{2\,(g)} + 1\ ½\ O_{2\,(g)}$	→	~~$3\ H_2O_{\,(l)}$~~	$3\ \Delta H_3$	

$3H_{2\,(g)} + 2C_{\,(s)} + ½\ O_{2\,(g)} \longrightarrow C_2H_5OH_{\,(l)}$

$\Delta H = -\Delta H_1 + 2\Delta H_2 + 3\Delta H_3 = 875 + 2(-394.51) + 3(-285.8) =$ **-771.4 kJ**

4. Calculate ΔH for the reaction $CH_{4\,(g)} + NH_{3\,(g)} \longrightarrow HCN_{\,(g)} + 3\ H_{2\,(g)}$, given:

$N_{2\,(g)} + 3\ H_{2\,(g)} \longrightarrow 2\ NH_3$ (g) ΔH = -91.8 kJ

$C_{\,(s)} + 2\ H_{2\,(g)} \longrightarrow CH_{4\,(g)}$ ΔH = -74.9 kJ

$H_{2\,(g)} + 2\ C_{\,(s)} + N_{2\,(g)} \longrightarrow 2\ HCN_{\,(g)}$ ΔH = +270.3 kJ

$N_{2\,(g)} + 3\ H_{2\,(g)}$	→	$2\ NH_{3\,(g)}$	ΔH_1	x -1/2
$C_{\,(s)} + 2\ H_{2\,(g)}$	→	$CH_{4\,(g)}$	ΔH_2	x -1
$H_{2\,(g)} + 2\ C_{\,(s)} + N_{2\,(g)}$	→	$2\ HCN_{\,(g)}$	ΔH_3	x ½
$NH_{3\,(g)}$	→	~~$½\ N_{2\,(g)}$~~ + $1\ ½\ H_{2\,(g)}$	$-½\ \Delta H_1$	
$CH_{4\,(g)}$	→	~~$C_{\,(s)} + 2\ H_{2\,(g)}$~~	$-1\ \Delta H_2$	
~~$½\ H_{2\,(g)}$~~ + ~~$C_{\,(s)}$~~ + ~~$½\ N_{2\,(g)}$~~	→	$2\ HCN_{\,(g)}$	$½\ \Delta H_3$	

$CH_{4\,(g)} + NH_{3\,(g)} \longrightarrow HCN_{\,(g)} + 3\ H_{2\,(g)}$, given:

$\Delta H = -½\ \Delta H_1 + -\Delta H_2 + ½\ \Delta H_3 = -½\ (-91.8) - (-74.9) + ½\ (270.3) =$ **256 kJ**

5. Calculate ΔH for the reaction $2\ Al_{(s)} + 3\ Cl_{2\ (g)} \rightarrow 2\ AlCl_{3\ (s)}$ from the data.

$2\ Al_{(s)} + 6\ HCl_{(aq)} \rightarrow 2\ AlCl_{3\ (aq)} + 3\ H_{2\ (g)}$	ΔH = -1049. kJ
$HCl_{(g)} \rightarrow HCl_{(aq)}$	ΔH = -74.8 kJ
$H_{2\ (g)} + Cl_{2\ (g)} \rightarrow 2\ HCl_{(g)}$	ΔH = -1845. kJ
$AlCl_{3\ (s)} \rightarrow AlCl_{3\ (aq)}$	ΔH = -323

$2\ Al_{(s)} + 6\ HCl_{(aq)}$	→	$2\ AlCl_{3\ (aq)} + 3\ H_{2\ (g)}$	ΔH_1	x 1
$HCl_{(g)}$	→	$HCl_{(aq)}$	ΔH_2	x 6
$H_{2\ (g)} + Cl_{2\ (g)}$	→	$2\ HCl_{(g)}$	ΔH_3	x 3
$AlCl_{3\ (s)}$	→	$AlCl_{3\ (aq)}$	ΔH_4	x -2
$2\ Al_{(s)} + \cancel{6\ HCl_{(aq)}}$	→	$\cancel{2\ AlCl_{3\ (aq)}} + \cancel{3\ H_{2\ (g)}}$	ΔH_1	
$\cancel{6\ HCl_{(g)}}$	→	$\cancel{6\ HCl_{(aq)}}$	$6\ \Delta H_2$	
$\cancel{3\ H_{2\ (g)}} + 3\ Cl_{2\ (g)}$	→	$\cancel{6\ HCl_{(g)}}$	$3\ \Delta H_3$	
$\cancel{2\ AlCl_{3\ (aq)}}$	→	$2\ AlCl_{3\ (s)}$	$-2\ \Delta H_4$	

$$2\ Al_{(s)} + 3\ Cl_{2\ (g)} \rightarrow 2\ AlCl_{3\ (s)}$$

$$\Delta H = \Delta H_1 + 6\ \Delta H_2 + 3\ \Delta H_3 - 2\ \Delta H_4 = \mathbf{-\ 6386.8\ kJ}$$

9. $\Delta H = \frac{1}{2}\ \Delta H_1 + 2\ \Delta H_2 - \Delta H_3 = -813$ kJ
10. $\Delta H = -\ \Delta H_1 - \Delta H_2 - \Delta H_3 = -96.6$ kJ
11. $\Delta H = \Delta H_1 - \Delta H_2 = +\ 98.8$ kJ
12. $\Delta H = 1/3\ \Delta H_1 - 1/3\ \Delta H_2 = -520$ kJ
13. $\Delta H = \Delta H_1 + \Delta H_2 - \Delta H_3 = -288.6$ kJ

14. Determine the heat of formation of liquid hydrogen peroxide at 25°C from the following thermochemical equations.

$H_{2\ (g)} + \frac{1}{2}\ O_{2\ (g)} \rightarrow H_2O_{(g)}$	ΔH = -241.82 kJ
$2\ H_{(g)} + O_{(g)} \rightarrow H_2O_{(g)}$	ΔH = -926.92 kJ
$2H_{(g)} + 2O_{(g)} \rightarrow H_2O_{2\ (g)}$	ΔH = - 1070.60 kJ
$2\ O_{(g)} \rightarrow O_{2\ (g)}$	ΔH = - 498.34 kJ
$H_2O_2\ (l) \rightarrow H_2O_{2\ (g)}$	ΔH = 51.46 kJ

Target: $H_{2\ (g)} + O_{2\ (g)} \rightarrow H_2O_{2\ (l)}$

$H_{2\ (g)} + \frac{1}{2}\ O_{2\ (g)}$	→	$H_2O_{(g)}$	ΔH_1	x 1
$2\ H_{(g)} + O_{(g)}$	→	$H_2O_{(g)}$	ΔH_2	x - 1
$2H_{(g)} + 2O_{(g)}$	→	$H_2O_{2\ (g)}$	ΔH_3	x 1
$2\ O_{(g)}$	→	$O_{2\ (g)}$	ΔH_4	x – ½
$H_2O_2\ (l)$	→	$H_2O_{2\ (g)}$	ΔH_5	x -1
$H_{2\ (g)} + \frac{1}{2}\ O_{2\ (g)}$	→	$\cancel{H_2O_{(g)}}$	ΔH_1	
$\cancel{H_2O_{2\ (g)}}$		$H_2O_2\ (l)$	$-\ \Delta H_5$	
$\cancel{2H_{(g)}} + \cancel{2O_{(g)}}$		$\cancel{H_2O_{2\ (g)}}$	ΔH_3	
$\cancel{H_2O_{(g)}}$	→	$\cancel{2\ H_{(g)}} + \cancel{O_{(g)}}$	$-\ \Delta H_2$	
$\frac{1}{2}\ O_{2\ (g)}$	→	$\cancel{O_{(g)}}$	$-\ \frac{1}{2}\ \Delta H_4$	

$$H_{2\ (g)} + O_{2\ (g)} \rightarrow H_2O_{2\ (l)}$$

$$\Delta H = \Delta H_1 - \Delta H_2 + \Delta H_3 - \frac{1}{2}\ \Delta H_4 - \Delta H_5 = \mathbf{-686.13\ kJ}$$