Chapter 7
Hess's Law

Textbook, p. 197 to 209

● **1.** *a)* 1) $NO_{2(g)} \rightarrow \frac{1}{2}N_{2(g)} + \cancel{O_{2(g)}} = \frac{1}{2}O_{2(g)}$ $\Delta H = -33.2$ kJ/mol

2) $\frac{1}{2}N_{2(g)} + \cancel{\frac{1}{2}O_{2(g)}} \rightarrow NO_{(g)}$ $\Delta H = +90.2$ kJ/mol

Overall reaction $NO_{2(g)} \rightarrow NO_{(g)} + \frac{1}{2}O_{2(g)}$ $\Delta H = +56.6$ kJ/mol

Answer: $NO_{2(g)} \rightarrow NO_{(g)} + \frac{1}{2}O_{2(g)}$ $\Delta H = +56.6$ kJ/mol

b) 1) $\cancel{CO_{2(g)}} + \cancel{2\,H_2O_{(l)}} \rightarrow CH_{4(g)} + \cancel{2\,O_{2(g)}}$ $\Delta H = +890.4$ kJ/mol

2) $C_{(s)} + \cancel{O_{2(g)}} \rightarrow \cancel{CO_{2(g)}}$ $\Delta H = -393.5$ kJ/mo

3) $2\,H_{2(g)} + \cancel{O_{2(g)}} \rightarrow \cancel{2\,H_2O_{(l)}}$ $\Delta H = -571.6$ kJ/mol

$C_{(s)} + 2\,H_{2(g)} \rightarrow CH_{4(g)}$ $\Delta H = -74.7$ kJ/mol

Answer: $C_{(s)} + 2\,H_{2(g)} \rightarrow CH_{4(g)}$ $\Delta H = -74.7$ kJ/mol

c)

1) $C_{12}H_{22}O_{11(s)} \rightarrow \cancel{12\,C_{(s)}} + \cancel{11\,H_{2(g)}} + \cancel{\frac{11}{2}O_{2(g)}}$ $\Delta H = +2225.5$ kJ/mol

2) $\cancel{11\,H_{2(g)}} + \cancel{\frac{11}{2}O_{2(g)}} \rightarrow 11\,H_2O_{(g)}$ $\Delta H = -2659.8$ kJ

3) $\cancel{12\,C_{(s)}} + 12\,O_{2(g)} \rightarrow 12\,CO_{2(g)}$ $\Delta H = -4722$ kJ

$C_{12}H_{22}O_{11(s)} + 12\,O_{2(g)} \rightarrow 12\,CO_{2(g)} + 11\,H_2O_{(g)}$ $\Delta H = -5156.3$ kJ

Answer: $C_{12}H_{22}O_{11(s)} + 12\,O_{2(g)} \rightarrow 12\,CO_{2(g)} + 11\,H_2O_{(g)}$ $\Delta H = -5156$ kJ/mol

d) 1) $H_2SO_{4\,(l)} \rightarrow \frac{1}{8}S_{8\,(s)} + H_{2\,(g)} + 2\,O_{2\,(g)} + \frac{1}{2}O_{2\,(g)}$ $\Delta H = +814.0$ kJ/mol

2) $H_{2\,(g)} + \frac{1}{2}O_{2\,(g)} \rightarrow H_2O_{\,(g)}$ $\Delta H = -241.8$ kJ/mol

3) $\frac{1}{8}S_{8\,(s)} + O_{2\,(g)} \rightarrow SO_{2\,(g)}$ $\Delta H = -296.8$ kJ/mol

$H_2SO_{4\,(l)} \rightarrow H_2O_{\,(g)} + SO_{2\,(g)} + \frac{1}{2}O_{2\,(g)}$ $\Delta H = +275.4$ kJ/mol

Answer: $H_2SO_{4\,(l)} \rightarrow H_2O_{\,(g)} + SO_{2\,(g)} + \frac{1}{2}O_{2\,(g)}$ $\Delta H = +275.4$ kJ/mol

e) 1) $H_2S_{\,(g)} \rightarrow H_{2\,(g)} + S_{\,(s)}$ $\Delta H = +20.6$ kJ/mol

2) $2\,H_{2\,(g)} + O_{2\,(g)} \rightarrow 2\,H_2O_{\,(g)}$ $\Delta H = -483.6$ kJ/mol

3) $S_{\,(s)} + O_{2\,(g)} \rightarrow SO_{2\,(g)}$ $\Delta H = -296.8$ kJ/mol

The first reaction and the third reaction are multiplied by 2.

1) $2\,H_2S_{\,(g)} \rightarrow 2\,H_{2\,(g)} + 2\,S_{\,(s)}$ $\Delta H = +41.2$ kJ

2) $2\,H_{2\,(g)} + O_{2\,(g)} \rightarrow 2\,H_2O_{\,(g)}$ $\Delta H = -483.6$ kJ/mol

3) $2\,S_{\,(s)} + 2\,O_{2\,(g)} \rightarrow 2\,SO_{2\,(g)}$ $\Delta H = -593.6$ kJ

$2\,H_2S_{\,(g)} + 3\,O_{2\,(g)} \rightarrow 2\,H_2O_{\,(g)} + 2\,SO_{2\,(g)}$ $\Delta H = -1036.0$ kJ

Answer: $2\,H_2S_{\,(g)} + 3\,O_{2\,(g)} \rightarrow 2\,H_2O_{\,(g)} + 2\,SO_{2\,(g)}$ $\Delta H = -518.0$ kJ/mol

● **2.** *1. Manipulation of equations to obtain an overall equation:*

The second reaction must be inverted and multiplied by 2.

$4\,CO_{2\,(g)} + 6\,H_2O_{\,(l)} \rightarrow 2\,C_2H_5OH_{\,(l)} + 6\,O_{2\,(g)}$ $\Delta H =$ +2733.6 kJ

2. Addition of the thermochemical equations:

1) $C_6H_{12}O_{6\,(s)} + 6\,O_{2\,(g)} \rightarrow 6\,CO_{2\,(g)} + 6\,H_2O_{\,(l)}$ $\Delta H = -2803.1$ kJ/mol

2) $4\,CO_{2\,(g)} + 6\,H_2O_{\,(l)} \rightarrow 2\,C_2H_5OH_{\,(l)} + 6\,O_{2\,(g)}$ $\Delta H =$ +2733.6 kJ

$C_6H_{12}O_{6\,(s)} + \rightarrow 2\,C_2H_5OH_{\,(l)} + 2\,CO_{2\,(g)}$ $\Delta H =$ -69.5 kJ

3. Conversion of the enthalpy value of the overall reaction into molar heat:

The molar heat -69.5 kJ for two moles of ethanol, that is, -34.75kJ/mol

Answer: The molar heat of the formation of ethanol (C_2H_5OH) is -34.75kJ/mol

● **3.** *1. Addition of the thermochemical equations:*

1) $2\,Al_{\,(s)} + \frac{3}{2}O_{2\,(g)} \rightarrow Al_2O_{3\,(s)}$ $\Delta H = -1675.7$ kJ/mol

2) $Fe_2O_{3\,(s)} \rightarrow 2\,Fe_{\,(s)} + \frac{3}{2}O_{2\,(g)}$ $\Delta H = +824.2$ kJ/mol

$Fe_2O_{3\,(s)} + 2\,Al_{\,(s)} \rightarrow Al_2O_{3\,(s)} + 2\,Fe_{\,(s)}$ $\Delta H = -851.5$ kJ

2. Conversion of the enthalpy value of the overall reaction into molar heat:

The molar heat is -851.5 kJ for one mole of Fe_2O_3, that is, -851.5 kJ/mol.

Answer: The molar heat of the reaction is -851.5 kJ/mol.

■ **5.** *a)* 4
b) 3
c) 4
d) 70 kJ/mol
e) 120 kJ/mol
f) +30 kJ/mol
g) −40 kJ/mol
h) Endothermic
i) −10 kJ/mol
j) Exothermic

■ **6.** *a) 1. Presentation of the equations of the elementary reactions:*

$\frac{1}{2}N_{2\,(g)} + \frac{1}{2}O_{2\,(g)} \rightarrow NO_{(g)} \qquad \Delta H = +90.2$ kJ/mol

$\frac{1}{2}N_{2\,(g)} + O_{2\,(g)} \rightarrow NO_{2\,(g)} \qquad \Delta H = +33.2$ kJ/mol

Refer to P.418

2. Manipulation of the equations to obtain the overall equation:
Reverse the first equation so that the $NO_{(g)}$ is on the reactant's side.

$NO_{(g)} \rightarrow \frac{1}{2}N_{2\,(g)} + \frac{1}{2}O_{2\,(g)} \qquad \Delta H = -90.2$ kJ/mol

3. Addition of the thermochemical equations:

1) $NO_{(g)} \rightarrow \frac{1}{2}N_{2\,(g)} + \frac{1}{2}O_{2\,(g)} \qquad \Delta H = -90.2$ kJ/mol

2) $\frac{1}{2}N_{2\,(g)} + O_{2\,(g)} \rightarrow \frac{1}{2}O_{2\,(g)} + NO_{2\,(g)} \qquad \Delta H = +33.2$ kJ/mol

$NO_{(g)} + \frac{1}{2}O_{2\,(g)} \rightarrow NO_{2\,(g)} \qquad \Delta H = -57.0$ kJ/mol

Answer: $NO_{(g)} + \frac{1}{2}O_{2\,(g)} \rightarrow NO_{2\,(g)} \qquad \Delta H = -57.0$ kJ/mol

b) 1. Presentation of the equations of the elementary reactions:

$C_{(s)} + O_{2\,(g)} \rightarrow CO_{2\,(g)} \qquad \Delta H = -393.5$ kJ/mol

$C_{(s)} + \frac{1}{2}O_{2\,(g)} \rightarrow CO_{(g)} \qquad \Delta H = -110.5$ kJ/mol

Refer to P.418

2. Manipulation of the equations to obtain an overall equation:
Reverse the second reaction so that the $CO_{(g)}$ is on the reactants' side.

$CO_{(g)} \rightarrow C_{(s)} + \frac{1}{2}O_{2\,(g)} \qquad \Delta H = +110.5$ kJ/mol

3. Addition of the thermochemical equations:

1) $C_{(s)} + O_{2\,(g)} \rightarrow \frac{1}{2}O_{2\,(g)} + CO_{2\,(g)} \qquad \Delta H = 393.5$ kJ/mol

2) $CO_{(g)} \rightarrow C_{(s)} + \frac{1}{2}O_{2\,(g)} \qquad \Delta H = +110.5$ kJ/mol

$CO_{(g)} + \frac{1}{2}O_{2\,(g)} \rightarrow CO_{2\,(g)} \qquad \Delta H = -283.0$ kJ/mol

Answer: $CO_{(g)} + \frac{1}{2}O_{2\,(g)} \rightarrow CO_{2\,(g)} \qquad \Delta H = -283.0$ kJ/mol

■ **7.** *1. Manipulation of the equations to obtain the overall equation:*

Reverse the first reaction so that the $C_2H_{2\,(g)}$ is on the products' side.

$2\,CO_{2\,(g)} + H_2O_{(l)} \rightarrow C_2H_{2\,(g)} + \frac{5}{2}O_{2\,(g)}$ $\quad \Delta H = +1299.6$ kJ/mol

Multiply the second reaction by 2.

$2\,C_{(s)} + 2\,O_{2\,(g)} \rightarrow 2\,CO_{2\,(g)}$ $\quad \Delta H = -787.0$ kJ

2. Addition of the thermochemical equations:

1) $2\,CO_{2\,(g)} + H_2O_{(l)} \rightarrow C_2H_{2\,(g)} + \frac{5}{2}O_{2\,(g)}$ $\quad \Delta H = +1299.6$ kJ/mol

2) $2\,C_{(s)} + 2\,O_{2\,(g)} \rightarrow 2\,CO_{2\,(g)}$ $\quad \Delta H = -787.0$ kJ

3) $H_{2\,(s)} + \frac{1}{2}O_{2\,(g)} \rightarrow H_2O_{(l)}$ $\quad \Delta H = -285.8$ kJ/mol

$2\,C_{(s)} + H_{2\,(s)} \rightarrow C_2H_{2\,(g)}$ $\quad \Delta H = 266.8$ kJ/mol

Answer: $2\,C_{(s)} + H_{2\,(s)} \rightarrow C_2H_{2\,(g)}$ $\quad \Delta H = 266.8$ kJ/mol

■ **8.** Graph *b)*.

■ **9.** *1. Choice of the correct equations:*

Reactions 2), 3) and 4) must be chosen to answer the question.

2. Manipulation of the equations to obtain the overall equation:

Multiply reaction 2) by 3.

$3\,C_{(s)} + 3\,O_{2\,(g)} \rightarrow 3\,CO_{2\,(g)} + 1180.5$ kJ

Reverse reaction 3) and multiply it by 4.

$4\,H_{2\,(g)} + 2\,O_{2\,(g)} \rightarrow 4\,H_2O_{(g)} + 967.2$ kJ

Reverse reaction 4).

$C_3H_{8\,(g)} + 104$ kJ $\rightarrow 3\,C_{(s)} + 4\,H_{2\,(g)}$

3. Addition of the thermochemical equations:

Add these three reactions algebraically to obtain the following overall reaction:

1) $3\,C_{(s)} + 3O_{2\,(g)} \rightarrow 3\,CO_{2\,(g)}$ $\quad \Delta H = -1180.5$ kJ

2) $4\,H_{2\,(g)} + 2\,O_{2\,(g)} \rightarrow 4\,H_2O_{(g)}$ $\quad \Delta H = -967.2$ kJ

3) $C_3H_{8\,(g)} \rightarrow 3\,C_{(s)} + 4\,H_{2\,(g)}$ $\quad \Delta H = +104.7$ kJ

$C_3H_{8\,(g)} + 5\,O_{2\,(g)} \rightarrow 3\,CO_{2\,(g)} + 4\,H_2O_{(g)}$ $\quad \Delta H = -2043.7$ kJ

Answer: $C_3H_{8\,(g)} + 5\,O_{2\,(g)} \rightarrow 3\,CO_{2\,(g)} + 4\,H_2O_{(g)}$ $\quad \Delta H = -2043.7$ kJ