# Enthalpy Answers

1. Given that:

   $CH_4\ (g) \longrightarrow C\ (s) + 2\ H_2\ (g) \quad \Delta H_r = 74.8\ kJ\ mol^{-1}$

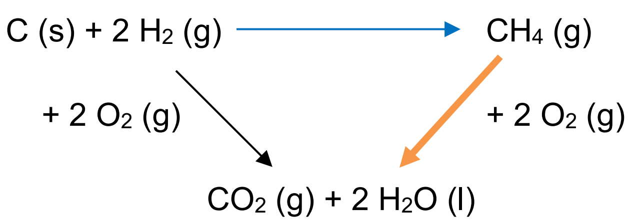
   What is the $\Delta H_f$ of $CH_4$ (g)?

   $-74.8\ kJ\ mol^{-1}$
   The required reaction is the reverse of formation, so as we are going in the opposite direction, it requires the opposite sign.

2. Calculate the $\Delta H_f$ of methane ($CH_4$ (g)), using the following $\Delta H_C$ data:

   $CH_4$ (g) = $-882\ kJ\ mol^{-1}$; C (s) = $-394\ kJ\ mol^{-1}$; $H_2$ (g) = $-286\ kJ\ mol^{-1}$

   Construct a Hess's Law cycle:




   We want $\Delta H_f$ which is the reaction going across the top (blue arrow). To get there we go down the black arrow and back up the orange arrow. We travel in the direction of the black arrow, but in the opposite direction for the orange arrow.

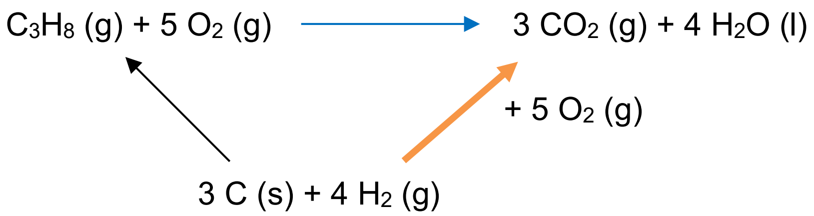
   So, we get: $C\ (s) + 2\ H_2\ (g) + 2\ O_2\ (g) \longrightarrow CO_2\ (g) + 2\ H_2O\ (l)$
   $-\ CH_4\ (g) + 2\ O_2\ (g) \longrightarrow CO_2\ (g) + 2\ H_2O\ (l)$
   $= (-394 + 2 \times (-286)) - (-882)\ kJ\ mol^{-1}$
   $= -84\ kJ\ mol^{-1}$

3. Calculate the $\Delta H_c$ of propane ($C_3H_8$ (g)), given the following:

   $C_3H_8$ (g) = $-104\ kJ\ mol^{-1}$; $CO_2$ (g) = $-394\ kJ\ mol^{-1}$;

$H_2O$ (l) $\Delta H_f$ = –286 kJ mol$^{-1}$

Construct a Hess's Law cycle:




We want $\Delta H_C$ which is the reaction going across the top (blue arrow). To get there we go down the black arrow and back up the orange arrow. We travel in the direction of the orange arrow, but in the opposite direction for the black arrow.

So, we get: – 3 C (s) + 4 $H_2$ (g) $\longrightarrow$ $C_3H_8$ (g)

+ 3 C (s) + 4 $H_2$ (g) + 5 $O_2$ (g) $\longrightarrow$ 3 $CO_2$ (g) + 4 $H_2O$ (l)

= – (–104) + 3 x (–394) + 4 x (–286)) kJ mol$^{-1}$

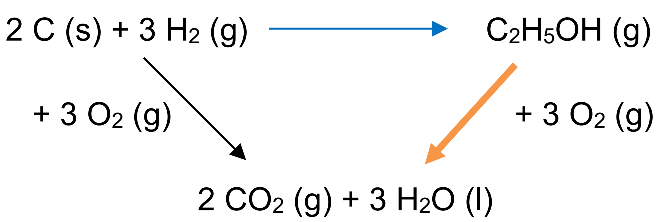
= 104 – 2326 kJ mol$^{-1}$

= –2222 kJ mol$^{-1}$

4. Calculate the $\Delta H_f$ of ethanol ($C_2H_5OH$ (l)), given the following:

$\Delta H_C$ of $C_2H_5OH$ (l) = –1371 kJ mol$^{-1}$
C (s) = –394 kJ mol$^{-1}$
$H_2$ (g) = –286 kJ mol$^{-1}$

Construct a Hess's Law cycle:




We want $\Delta H_f$ which is the reaction going across the top (blue arrow). To get there we need to go down the black arrow and back up the orange arrow. We travel in the direction of the black arrow, but in the opposite direction for the orange arrow.

So, we get: 2 C (s) + 3 $H_2$ (g) + 3 $O_2$ (g) $\longrightarrow$ 2 $CO_2$ (g) + 3 $H_2O$ (l)

$$-\ C_2H_5OH\ (g) + 3\ O_2\ (g) \longrightarrow 2\ CO_2\ (g) + 3\ H_2O\ (l)$$
$= (2 \times (-394) + 3 \times (-286)) - (-1371)$ kJ mol$^{-1}$
$= -275$ kJ mol$^{-1}$

5. Given the bond enthalpies:

   C–C = 348 kJ mol$^{-1}$; C–H = 412 kJ mol$^{-1}$; O=O = 496 kJ mol$^{-1}$;
   C–O = 336 kJ mol$^{-1}$; C=O = 743 kJ mol$^{-1}$; O–H = 463 kJ mol$^{-1}$

   Find the $\Delta H_r$ of the following reaction:

   $$CH_3COOH\ (l) + 3\ O_2\ (g) \longrightarrow 2\ CO_2\ (g) + 2\ H_2O\ (l)$$

   For this question we need to take a different approach. The $\Delta H_r$ will be equal to the total number of bonds broken minus the total number of bonds made (as breaking bonds requires energy and making bonds gives out energy).

   | **Bonds broken** | **Bonds made** |
   |---|---|
   | 3 C–H | 4 C=O |
   | 1 C=O | 4 O–H |
   | 1 C–O | |
   | 1 O–H | |
   | 1 C–C | |
   | 3 O=O | |

   A C=O and an O–H bond are both made and broken, thus cancelling each other out, so we get:

   | **Bonds broken** | | **Bonds made** | |
   |---|---|---|---|
   | 3 C–H | 3 x (412) | 3 C=O | 3 x (743) |
   | 1 C–O | 336 | 3 O–H | 3 x (463) |
   | 1 C–C | 348 | | |
   | 3 O=O | 3 x (496) | | |

   Total broken = 3408 Total made = 3618

   Bonds broken – Bonds made = 3408 – 3618 = –210 kJ mol$^{-1}$

6. Given the following:

   $\Delta H_C$ of maltose ($C_{12}H_{22}O_{11}$ (s)) = –5670 kJ mol$^{-1}$

Calculate the $\Delta H_C$ of glucose ($C_6H_{12}O_6$ (s)):

$$2\,C_6H_{12}O_6\,(s) \longrightarrow C_{12}H_{22}O_{11}\,(s) + H_2O\,(l) \qquad \Delta H_r = +54\ \text{kJ mol}^{-1}$$

Construct a Hess's Law cycle:

$$\begin{tikzcd}
2\,C_6H_{12}O_6\,(s) + 12\,O_2\,(g) \arrow[rr] \arrow[dr] & & 12\,CO_2\,(g) + 12\,H_2O\,(l) \\
& C_{12}H_{22}O_{11}\,(s) + H_2O\,(l) \arrow[ur, "+12\,O_2\,(g)"'] &
\end{tikzcd}$$

We want $\Delta H_C$ which is the reaction going across the top (blue arrow). To get there we go down the black arrow and back up the orange arrow. We travel in the direction of both arrows.

So, we get: $2\,C_6H_{12}O_6\,(s) \longrightarrow C_{12}H_{22}O_{11}\,(s) + H_2O\,(l)$

$+\ C_{12}H_{22}O_{11}\,(s) + H_2O\,(l) \longrightarrow 12\,CO_2\,(g) + 12\,H_2O\,(l)$

$= 54 + -5670\ \text{kJ mol}^{-1}$

$= 5616\ \text{kJ mol}^{-1}$

But this is for

$2\,C_6H_{12}O_6\,(s) \longrightarrow 12\,CO_2\,(g) + 12\,H_2O\,(l)$,

and the $\Delta H_C$ of glucose ($C_6H_{12}O_6$ (s)) only requires one, so we halve this value to give $-2808\ \text{kJ mol}^{-1}$.