Hess's Law Problems

Q1 2-Methylpropan-1-ol can also be converted to produce diesel and jet fuel.

The first step in the process is the production of 2-methylpropene.

$$\underset{\textit{2-methylpropan-1-ol}}{C_4H_{10}O_{(l)}} \rightarrow \underset{\textit{2-methylpropene}}{C_4H_{8(g)}} + H_2O_{(g)}$$

Using the data below, calculate the enthalpy change, in kJ mol^{-1}, for the production of 2-methylpropene from 2-methylpropan-1-ol.

$$4C_{(s)} + 5H_{2(g)} + \tfrac{1}{2}O_{2(g)} \rightarrow C_4H_{10}O_{(l)} \qquad \Delta H = -335 \text{ kJ mol}^{-1}$$
$$4C_{(s)} + 4H_{2(g)} \rightarrow C_4H_{8(g)} \qquad \Delta H = -17 \text{ kJ mol}^{-1}$$
$$H_{2(g)} + \tfrac{1}{2}O_{2(g)} \rightarrow H_2O_{(g)} \qquad \Delta H = -242 \text{ kJ mol}^{-1}$$

2

Q2 When in danger, bombardier beetles can fire a hot, toxic mixture of chemicals at their attacker. This mixture contains quinone, $C_6H_4O_2$, a compound that is formed by the reaction of hydroquinone, $C_6H_4(OH)_2$, with hydrogen peroxide, H_2O_2.

The equation for the overall reaction is:

$$C_6H_4(OH)_{2(aq)} + H_2O_{2(aq)} \rightarrow C_6H_4O_{2(aq)} + 2H_2O_{(\ell)}$$

Use the following data to calculate the enthalpy change, in kJ mol^{-1}, for the above reaction.

$$C_6H_4(OH)_{2(aq)} \rightarrow C_6H_4O_{2(aq)} + H_{2(g)} \qquad \Delta H = +177{\cdot}4 \text{ kJ mol}^{-1}$$
$$H_{2(g)} + O_{2(g)} \rightarrow H_2O_{2(aq)} \qquad \Delta H = -191{\cdot}2 \text{ kJ mol}^{-1}$$
$$H_{2(g)} + \tfrac{1}{2}O_{2(g)} \rightarrow H_2O_{(g)} \qquad \Delta H = -241{\cdot}8 \text{ kJ mol}^{-1}$$
$$H_2O_{(g)} \rightarrow H_2O_{(\ell)} \qquad \Delta H = -43{\cdot}8 \text{ kJ mol}^{-1}$$

3

Q3 Self-heating cans may be used to warm drinks such as coffee. When the button on the can is pushed, a seal is broken, allowing water and calcium oxide to mix and react.

The reaction produces solid calcium hydroxide and releases heat. If more water is used the calcium hydroxide is produced as a solution instead of as a solid.

The equation for the reaction is:

$$CaO_{(s)} + H_2O_{(\ell)} \rightarrow Ca(OH)_{2(aq)}$$

Using the following data, calculate the enthalpy change, in kJ mol^{-1}, for this reaction.

$$Ca_{(s)} + \tfrac{1}{2}O_{2(g)} \rightarrow CaO_{(s)} \qquad \Delta H = -635 \text{ kJ mol}^{-1}$$
$$H_{2(g)} + \tfrac{1}{2}O_{2(g)} \rightarrow H_2O_{(\ell)} \qquad \Delta H = -286 \text{ kJ mol}^{-1}$$
$$Ca_{(s)} + O_{2(g)} + H_{2(g)} \rightarrow Ca(OH)_{2(s)} \qquad \Delta H = -986 \text{ kJ mol}^{-1}$$
$$Ca(OH)_{2(s)} \rightarrow Ca(OH)_{2(aq)} \qquad \Delta H = -82 \text{ kJ mol}^{-1}$$

2

Q4 Mobile phones are being developed that can be powered by methanol. Methanol can be made by a two-stage process.

In the first stage, methane is reacted with steam to produce a mixture of carbon monoxide and hydrogen.

$$CH_{4(g)} + H_2O_{(g)} \rightarrow CO_{(g)} + 3H_{2(g)}$$

Use the data below to calculate the enthalpy change, in kJ mol^{-1}, for the forward reaction.

$$CO_{(g)} + \tfrac{1}{2}O_{2(g)} \rightarrow CO_{2(g)} \qquad \Delta H = -283 \text{ kJ mol}^{-1}$$

$$H_{2(g)} + \tfrac{1}{2}O_{2(g)} \rightarrow H_2O_{(g)} \qquad \Delta H = -242 \text{ kJ mol}^{-1}$$

$$CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(g)} \qquad \Delta H = -803 \text{ kJ mol}^{-1}$$ **2**

Q5 The compound diborane (B_2H_6) is used as a rocket fuel. The equation for the combustion of diborane is shown below.

$$B_2H_{6(g)} + 3O_{2(g)} \rightarrow B_2O_{3(s)} + 3H_2O_{(\ell)}$$

Calculate the enthalpy of combustion of diborane (B_2H_6) in kJ mol^{-1}, using the following data.

$$2B_{(s)} + 3H_{2(g)} \rightarrow B_2H_{6(g)} \qquad \Delta H = 36 \text{ kJ mol}^{-1}$$

$$H_{2(g)} + \tfrac{1}{2}O_{2(g)} \rightarrow H_2O_{(\ell)} \qquad \Delta H = -286 \text{ kJ mol}^{-1}$$

$$2B_{(s)} + 1\tfrac{1}{2}O_{2(g)} \rightarrow B_2O_{3(s)} \qquad \Delta H = -1274 \text{ kJ mol}^{-1}$$ **2**

Q6 The industrial method currently used to produce butan-2-ol is the hydration of but-2-ene.

$$C_4H_{8(g)} + H_2O_{(g)} \rightarrow C_4H_{10}O_{(g)}$$

The enthalpy values for the following reactions are:

$$4C_{(s)} + 4H_{2(g)} \rightarrow C_4H_{8(g)} \qquad \Delta H = -7{\cdot}1 \text{ kJ mol}^{-1}$$

$$4C_{(s)} + 5H_{2(g)} + \tfrac{1}{2}O_{2(g)} \rightarrow C_4H_{10}O_{(g)} \qquad \Delta H = -292{\cdot}8 \text{ kJ mol}^{-1}$$

$$2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(g)} \qquad \Delta H = -483{\cdot}6 \text{ kJ mol}^{-1}$$

Using the data above, calculate the enthalpy change, in kJ mol^{-1}, for the production of butan-2-ol by hydration of but-2-ene. **2**

Q7 Enthalpy changes can also be calculated using Hess's Law. The enthalpy of formation for pentan-1-ol is shown below.

$$5C_{(s)} + 6H_{2(g)} + O_{2(g)} \rightarrow C_5H_{11}OH_{(\ell)} \qquad \Delta H = -354 \text{ kJ mol}^{-1}$$

Using this value, and the enthalpies of combustion of carbon and hydrogen from the data booklet, calculate the enthalpy of combustion of pentan-1-ol, in kJ mol^{-1}. **2**

Q8 Glycerol, $C_3H_8O_3$, is widely used as an ingredient in toothpaste and cosmetics.

The enthalpy of formation of glycerol is the enthalpy change for the reaction:

$$3C_{(s)} \text{ (}graphite\text{)} + 4H_{2(g)} + 1\tfrac{1}{2}O_{2(g)} \rightarrow C_3H_8O_{3(\ell)}$$

Calculate the enthalpy of formation of glycerol, in kJ mol^{-1}, using information from the data booklet and the following data.

$$C_3H_8O_{3(\ell)} + 3\tfrac{1}{2}O_{2(g)} \rightarrow 3CO_{2(g)} + 4H_2O_{(\ell)} \quad \Delta H = -1654 \text{ kJ mol}^{-1}$$ **2**

Q9 Silane, silicon hydride, is formed in the reaction of silicon with hydrogen.

$$Si_{(s)} + 2H_{2(g)} \rightarrow \underset{\text{silane}}{SiH_{4(g)}}$$

The enthalpy change for this reaction is called the enthalpy of formation of silane.

The combustion of silane gives silicon dioxide and water.

$$SiH_{4(g)} + 2O_{2(g)} \rightarrow SiO_{2(s)} + 2H_2O_{(\ell)} \quad \Delta H = -1517 \text{ kJ mol}^{-1}$$

The enthalpy of combustion of silicon is –911 kJ mol^{-1}.

Use this information and the enthalpy of combustion of hydrogen in the data booklet to calculate the enthalpy of formation of silane, in kJ mol^{-1}. **2**

Q10 The equation for the enthalpy of formation of ethyne is:

$$2C_{(s)} + H_{2(g)} \rightarrow C_2H_{2(g)}$$

Use the enthalpies of combustion of carbon, hydrogen and ethyne given in the data booklet to calculate the enthalpy of formation of ethyne, in kJ mol–1. **2**

Q11 Hess's Law can be used to obtain enthalpy changes for reactions that cannot be measured directly.

Use the following enthalpy changes

$$KClO_{3(s)} + 3Mg_{(s)} \rightarrow KClO_{3(s)} + 3MgO_{(s)} \quad \Delta H = -1852 \text{ kJ mol}^{-1}$$

$$K_{(s)} + \tfrac{1}{2}Cl_{2(g)} \rightarrow KCl_{(s)} \quad \Delta H = -437 \text{ kJ mol}^{-1}$$

$$Mg_{(s)} + \tfrac{1}{2}O_{2(g)} \rightarrow MgO_{(s)} \quad \Delta H = -602 \text{ kJ mol}^{-1}$$

to calculate the enthalpy change in kJ mol^{-1}, for the reaction:

$$K_{(s)} + \tfrac{1}{2}Cl_{2(g)} + 1\tfrac{1}{2}O_{2(g)} \rightarrow KClO_{3(s)}$$ **2**

Q1 $\Delta H = [+ 335 + (-17) + (-242)]$ (***1 mark***) $= (+) 76$ (kJ mol^{-1}) (***1 mark***)

Sign and units need not be given in answer but if given must be correct

Q2 -202·6 kJ mol^{-1} (ignore units) (***3 marks***) 177·4 + 191·2 + 2(-241·8) + 2(-43·8)

- reversing peroxide equation (1 *mark*).
- doubling water formation and condensation equations (1 *mark*).
- correct additions (1 *mark*).

Q3 – 147 kJ mol^{-1} (***2 marks***) 1 *mark* is awarded for 2 out of the four following numbers
+ 635 + 286 − 986 − 82

Q4 +206 kJ mol^{-1} (***2 marks***) 1 *mark* is awarded for 2 out of the three following numbers
−803 + 726 + 283

Q5 -2168 (kJ mol^{-1}) (***2 marks***) 1 *mark* for 2 from the three correct enthalpy change values:
-36 kJ -1274 kJ 3 x -286 (= -858) kJ

Q6 –43·9 (***2 marks***) 1 *mark* for 2 values from this list +7·1 +241·8 -292·8

Q7 -3332 (***2 marks***) 1 *mark* for 2 from the three correct enthalpy change values:
+354 -5×394 or -1970 -6×286 or -1716

Q8 –672 kJ mol^{-1} (***2 marks***) 1 *mark* for 2 from the three correct enthalpy change values:

$3C + 3O_2 \rightarrow 3CO_2$ $-394 \times 3 = -1182$ kJ

$4H_2 + 2O_2 \rightarrow 4H_2O$ $-286 \times 4 = -1144$ kJ

$3CO_2 + 4H_2O \rightarrow C_3H_8O_3 + {}^{7}/_{2}\, O_2 = +1654$ kJ

Q9 34 kJ mol^{-1} (***2 marks***) 1 *mark* for 2 from the three correct enthalpy change values:

$SiO_{2(s)} + 2H_2O_{(\ell)} \rightarrow SiH_{4(g)} + 2O_{2(g)}$ +1517 kJ

$Si_{(s)} + O_{2(g)} \rightarrow SiO_{2(s)}$ - 911 kJ

$2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(g)}$ - 572 kJ

Q10 +226 kJ mol^{-1} (***2 marks***) 1 *mark* for 2 from the three correct enthalpy change values:

ΔH_c carbon x 2 = -394 kJ x 2 = -788 kJ

ΔH_c hydrogen -286 kJ

reverse ΔH_c ethyne = +1300 kJ

Q11 -391 kJ mol^{-1} (***2 marks***) 1 *mark* for 2 from the three correct enthalpy change values:

rev ① 1852 kJ unchanged ② -437 kJ 3 *x* ③ -1806 kJ