AP CHEMISTRY

TOPIC 9: THERMODYNAMICS, PART B, Day 109:

- Hess's law
- Enthalpy of Formation
- Spontaneity
- Entropy
- Heat Capacity

A past AP question within the last five years: with some parts to help "jog the memory" again !!!

In an experiment, a sample of an unknown, pure gaseous hydrocarbon was analyzed. Results showed that the sample contained 6.000 g of carbon and 1.344 g of hydrogen.

(a) Determine the empirical formula of the hydrocarbon.

$$\frac{6.000\ g}{} \times \frac{1\ mol\ C}{12.011\ g} = 0.50\ mol\ C \quad ; \quad \frac{0.50\ mol}{0.50\ mol} = 1 \times 3 = 3$$

$$\frac{1.344\ g}{} \times \frac{1\ mol\ H}{1.008\ g} = 1.3\bar{3}\ mol\ H \quad ; \quad \frac{1.33\ mol}{0.50\ mol} = 2\frac{2}{3} \times 3 = 8$$

$$\boxed{C_3H_8}$$

(b) The density of the hydrocarbon at 25 ^{0}C and 1.09 atm is 1.96 g L^{-1}.

(i) Calculate the molar mass of the hydrocarbon.

$$PV = nRT \quad ; \quad PV = \frac{m}{M}RT$$

$$M = \left(\frac{m}{V}\right) \times \frac{RT}{P} = \left(\frac{1.96\ g}{L}\right) \times \left(\frac{(0.0821\ atm \cdot L)(298\ K)}{(mol \cdot K)1.09\ atm}\right) = 44\frac{g}{mol}$$

(ii) Determine the molecular formula of the hydrocarbon.

$$(\ C_3H_8\ )_n$$

$$n = \frac{molecular\ formula\ mass}{empirical\ formula\ mass} = \frac{44\ g}{44\ g} = 1$$

$$(\ C_3H_8\ )_1 = C_3H_8$$

In another experiment, liquid heptane, $C_7H_{16\,(l)}$, is completely combusted to produce $CO_{2\,(g)}$ and $H_2O_{\,(l)}$ as represented by the following equation below:

$$C_7H_{16\,(l)} + 11\ O_{2\,(g)} \rightarrow 7\ CO_{2\,(g)} + 8\ H_2O_{\,(l)}$$

The heat of combustion, ΔH^0_{comb}, for one mole of $C_7H_{16\,(l)}$ is - 4850 kJ

(c) Using the information in the table below, calculate the value of ΔH^0_f for $C_7H_{16\,(l)}$ in kJ mol^{-1}.

Compound	ΔH^0_f (kJ mol^{-1})
$CO_{2\,(g)}$	- 393.5
$H_2O_{\,(l)}$	- 285.8
$O_{2\,(g)}$	0

$$\Delta H^0_{rxn} = \Sigma H^0_f \text{ (products)} - \Sigma H^0_f \text{ (reactants)}$$

$$\Delta H^0_{comb.} = [\,7\,\Delta H^0_f\,(CO_2) + 8\,\Delta H^0_f\,(H_2O)\,] - [\,\Delta H^0_f\,(C_7H_{16}) + 0\,] = -4850\ \text{kJ mol}^{-1}$$

$$[\,7\,(-393.5\ \text{kJ mol}^{-1}) + 8\,(-285.8\ \text{kJ mol}^{-1})\,] - [\,\Delta H^0_f\,(C_7H_{16})\,] = -4850\ \text{kJ mol}^{-1}$$

$$\Delta H^0_f\,(C_7H_{16}) = [\,7\,(-393.5\ \text{kJ mol}^{-1}) + 8\,(-285.8\ \text{kJ mol}^{-1})\,] + 4850\ \text{kJ mol}^{-1}$$

$$\Delta H^0_f\,(C_7H_{16}) = [\,-5049\ \text{kJ mol}^{-1}\,] + 4850\ \text{kJ mol}^{-1} = -190.9\ \text{kJ mol}^{-1}$$

$$\Delta H^0_f\,(C_7H_{16}) = -190.9\ \text{kJ mol}^{-1} \quad ; \quad \boldsymbol{\Delta H^0_f\,(C_7H_{16}) = -190.9\ \text{kJ mol}^{-1}}$$

(d) A 0.0108 mol sample of $C_7H_{16\,(l)}$ is combusted in a bomb calorimeter.

(i) Calculate the amount of heat released to the calorimeter.

$$\Delta H^0_{combustion}\,(C_7H_{16}) = -4850\ \text{kJ mol}^{-1}$$

$$\frac{0.0108\ mol\ C_7H_{16}}{} \times \frac{-4850\ kJ}{mol} = -52.4\ kJ$$

(ii) Given that the total heat capacity of the calorimeter is 9.273 kJ $^0C^{-1}$, calculate the temperature change of the calorimeter.

The question wants the change for the calorimeter…

Amount of energy **ABSORBED** by the calorimeter was 52.4 kJ

$$C_p = \frac{\Delta H}{\Delta T} \quad ; \quad \Delta T = \frac{\Delta H}{C_p} = \frac{52.4\ kJ\ (^0C)}{9.273\ kJ} = 5.65\ ^0C$$

2) Calculate ΔH^0 for this reaction:

$$6\,C_{(s)} + 6\,H_{2\,(g)} + 3\,O_{2\,(g)} \rightarrow C_6H_{12}O_{6\,(g)} \quad \Delta H^0 = ???$$

using the following equations:

$$C_{(s)} + O_{2\,(g)} \rightarrow CO_{2\,(g)} \quad \Delta H^0 = -393.51\ kJ$$

$$H_{2\,(g)} + \frac{1}{2} O_{2\,(g)} \rightarrow H_2O_{(l)} \quad \Delta H^0 = -285.83\ kJ$$

$$C_6H_{12}O_{6\,(g)} + 6\,O_{2\,(g)} \rightarrow 6\,CO_{2\,(g)} + 6\,H_2O_{(l)} \quad \Delta H^0 = -2803.02\ kJ$$

Answer

$$6\,(\,C_{(s)} + O_{2\,(g)} \rightarrow CO_{2\,(g)}\,) \qquad \Delta H^0 = 6\,(-393.51\text{ kJ}) = -2361.06\text{ kJ}$$

$$6\,(\,H_{2\,(g)} + \frac{1}{2} O_{2\,(g)} \rightarrow H_2O_{(l)}\,) \qquad \Delta H^0 = 6\,(-285.83\text{ kJ}) = -1714.98\text{ kJ}$$

$$6\,CO_{2\,(g)} + 6\,H_2O_{(l)} \rightarrow C_6H_{12}O_{6\,(g)} + 6\,O_{2\,(g)} \qquad \Delta H^0 = +2803.02\text{ kJ}$$

CHANGES TO ...

Answer

$$6\,C_{(s)} + \cancel{6\,O_{2\,(g)}} \rightarrow \cancel{6\,CO_{2\,(g)}} \qquad \Delta H^0 = -2361.06\text{ kJ}$$

$$6\,H_{2\,(g)} + 3\,O_{2\,(g)} \rightarrow \cancel{6\,H_2O_{(l)}}\,) \qquad \Delta H^0 = -1714.98\text{ kJ}$$

$$\cancel{6\,CO_{2\,(g)}} + \cancel{6\,H_2O_{(l)}} \rightarrow C_6H_{12}O_{6\,(g)} + \cancel{6\,O_{2\,(g)}} \qquad \Delta H^0 = +2803.02\text{ kJ}$$

$$6\,C_{(s)} + 6\,H_{2\,(g)} + 3\,O_{2\,(g)} \rightarrow C_6H_{12}O_{6\,(g)} \qquad \Delta H^0 = -1273.02\text{ kJ}$$