Worked answers to Energetics

Question 1: Enthalpy Changes 1
Looking at the graphs and equations shown below, identify which graph belongs to which reaction. State which process is exothermic and which is endothermic. Reaction 1 has a $\Delta_r H$ value of +126 kJ mol$^{-1}$ and reaction 2 has a $\Delta_r H$ value of -107 kJ mol$^{-1}$.

A is the graph for reaction 2 and is exothermic. The $\Delta_r H$ is negative and therefore heat is given out during the reaction. B is the graph for reaction 1 and is endothermic. The $\Delta_r H$ is positive and therefore heat is taken in during the reaction.

Question 2: Enthalpy Changes 2
In an experiment, 2 g of methanol was burned completely in air.
The enthalpy changes of formation are as follows:

<table>
<thead>
<tr>
<th>Substance</th>
<th>Standard Enthalpy Change of Formation ($\Delta f H$) / kJ mol$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH$_3$OH (l)</td>
<td>-234</td>
</tr>
<tr>
<td>CO$_2$ (g)</td>
<td>-394</td>
</tr>
<tr>
<td>H$_2$O (l)</td>
<td>-286</td>
</tr>
</tbody>
</table>

a) Write an equation for the combustion of methanol.

CH$_3$OH (l) + 1½O$_2$ (g) $\rightarrow$ CO$_2$ (g) + 2H$_2$O (l)

b) Using your equation and the data given above, calculate the $\Delta_c H$ for methanol. (Hint: consider using a Hess law cycle)

$$\Delta c H = \Sigma v \Delta f H_{(products)} - \Sigma v \Delta f H_{(reactants)}$$

$$\Delta c H = (-394 + (2 \times -286)) \text{ kJ mol}^{-1} - (-234 \text{ kJ mol}^{-1})$$

$$\Delta c H = -732 \text{ kJ mol}^{-1}$$

c) Comment on whether this is an endothermic or exothermic reaction (using your answer to (b)).

This reaction is exothermic. The negative sign indicates that heat is released during the reaction.

Question 3: Enthalpy Changes 3
The enthalpy change of formation of NaCl was under investigation. 75 cm$^3$ of 1 M HCl was poured into a beaker then 75 cm$^3$ NaOH was added to the HCl.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Standard Enthalpy Change of Formation / kJ mol$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>H$_2$O (l)</td>
<td>-286</td>
</tr>
<tr>
<td>HCl (aq)</td>
<td>-167</td>
</tr>
<tr>
<td>NaOH (aq)</td>
<td>-425</td>
</tr>
<tr>
<td>NaCl (aq)</td>
<td>-411</td>
</tr>
</tbody>
</table>

a) Write an equation for the neutralisation of HCl by NaOH.

HCl (aq) + NaOH (aq) $\rightarrow$ NaCl (aq) + H$_2$O (l)
b) Using your equation and the data given above, calculate the $\Delta_r H$ of this reaction. (Hint: draw a Hess law cycle)

$\Delta_r H = \Sigma v \Delta H_{\text{products}} - \Sigma v \Delta H_{\text{reactants}}$

$\Delta_r H = (-411 + -286) \text{ kJ mol}^{-1} - (-425 + -167) \text{ kJ mol}^{-1}$

$\Delta_r H = -697 \text{ kJ mol}^{-1} - (-592) \text{ kJ mol}^{-1}$

$\Delta_r H = -105 \text{ kJ mol}^{-1}$

c) Comment on the sign and magnitude of the value calculated in part (b).
The negative sign indicates that heat is created and given out during the reaction and consequently the reaction is exothermic.

Question 4: Bond Enthalpy

\[ \text{C}_3\text{H}_8 + 5\text{O}_2 \rightarrow 3\text{CO}_2 + 4\text{H}_2\text{O} \]

<table>
<thead>
<tr>
<th>Bond</th>
<th>C – H</th>
<th>C – C</th>
<th>O = O</th>
<th>C = O</th>
<th>O – H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Bond enthalpy / kJ mol(^{-1})</td>
<td>+413</td>
<td>+347</td>
<td>+498</td>
<td>+743</td>
<td>+464</td>
</tr>
</tbody>
</table>

\[ \text{a)} \text{ Using the bond enthalpies and the equation shown above, calculate the } \Delta H \text{ for the combustion of pentane.} \]

$\Delta H = \Sigma (\text{enthalpy of bonds broken}) - \Sigma (\text{enthalpy of bonds formed})$

$\Delta H_{\text{bonds broken}} = ((8 \times \text{C – H}) + (2 \times \text{C – C}) + (5 \times \text{O = O}))$

$\Delta H_{\text{bonds broken}} = ((8 \times 413) + (2 \times 347) + (5 \times 498)) \text{ kJ mol}^{-1}$

$\Delta H_{\text{bonds broken}} = 6488 \text{ kJ mol}^{-1}$

$\Delta H_{\text{bonds formed}} = ((6 \times \text{C = O}) + (8 \times \text{O – H}))$

$\Delta H_{\text{bonds formed}} = ((6 \times 743) + (8 \times 464)) \text{ kJ mol}^{-1}$

$\Delta H_{\text{bonds formed}} = 8170 \text{ kJ mol}^{-1}$

$\Delta H = 6488 \text{ kJ mol}^{-1} - 8170 \text{ kJ mol}^{-1}$

$\Delta H = -1682 \text{ kJ mol}^{-1}$

\[ \text{b)} \text{ Draw an energy diagram for the forward reaction (like the diagrams in question 1), labelling the reactants, products, } \Delta H \text{ and stating whether it is an exothermic or endothermic reaction.} \]

$\Delta H$ is negative therefore the reaction is exothermic.

Question 5: Mole calculations 1

\[ \text{a)} \text{ How many moles are there in 3.75 g of benzene?} \]

Benzene $\text{C}_6\text{H}_6 \text{ Mr} = ((6 \times 12) + (6 \times 1)) \text{ g mol}^{-1} = 78 \text{ g mol}^{-1}$

Moles = Mass / Mr

Moles = 3.75 g / 78 g mol\(^{-1}\)

Moles = 0.0480 moles

\[ \text{b)} \text{ If 3.75 g of benzene was dissolved in water such that the total volume was } 150 \text{ cm}^3, \text{ what would the resulting concentration be?} \]
Concentration = Moles / Volume
Concentration = 0.0480 moles / (150 / 1000) dm$^3$
Concentration = 0.320 mol dm$^{-3}$

**Question 6: Concentration Calculations**

a) 15 g of propan-1-ol was added to 15 cm$^3$ of H$_2$O. Given that the density of propan-1-ol is 0.804 g cm$^{-3}$ calculate the volume of propan-1-ol added to the solution and hence the total volume of the resulting solution.

Volume = Mass / Density
Volume = 15.0 g / 0.804 g cm$^{-3}$
Volume = 18.66 cm$^3$ = 18.7 cm$^3$ (3 s.f.)
Total volume is 15.0 cm$^3$ + 18.7 cm$^3$ = 33.7 cm$^3$.

b) Using your answer from part (a), calculate the number of moles of propan-1-ol in the solution.

Propan-1-ol Mr = ((3 x 12) + (8 x 1) + (16 x 1)) g mol$^{-1}$ = 60 g mol$^{-1}$.
Moles = Mass / Mr
Moles = 15.0 g / 60 g mol$^{-1}$
Moles = 0.25 moles.

c) Calculate the concentration of the resulting solution in mol dm$^{-3}$.
Concentration = moles / volume
Concentration = 0.25 mol / 33.7 cm$^3$
Concentration = 7.4 x 10$^{-3}$ mol cm$^{-3}$.

**Question 7: Mole Calculations**

60 cm$^3$ of 2.3 M NaOH was added to 300 cm$^3$ of H$_2$O making solution A. 25 cm$^3$ of solution A was removed by pipette and added to 40 cm$^3$ of H$_2$O in a different beaker making solution B.

a) Calculate the concentration of NaOH in solution A.

\[
C_1 V_1 = C_2 V_2
\]
2.3 mol dm$^{-3}$ x 60.0 cm$^3$ = 360 cm$^3$ x $C_2$
$C_2$ x 360 cm$^3$ = 138 mol dm$^{-3}$ cm$^3$
$C_2$ = 0.383 mol dm$^{-3}$

b) Calculate the resulting concentration of solution B after pipetting.

\[
C_1 V_1 = C_2 V_2
\]
0.383 mol dm$^{-3}$ x 25.0 cm$^3$ = 65.0 cm$^3$ x $C_2$
$C_2$ x 65 cm$^3$ = 9.58 mol dm$^{-3}$ cm$^3$
$C_2$ = 0.147 mol dm$^{-3}$