CHEMISTRY 30
REVIEW

1) After coming in from outside, a student makes a cup of instant hot chocolate by heating water in a microwave. What is the gain in thermal energy if a cup (250 mL) of tap water is increased in temperature from 15°C to 95°C?

\[
Q = mcA_f = (250 \text{g})(4.18 \text{J/g°C})(95 - 15°C) = 83800 \text{J} \\
= 83.8 \text{kJ}
\]

2) In a laboratory investigation into the neutralization reaction:

\[
\text{Ba(NO}_3\text{)}_2(\text{aq}) + \text{K}_2\text{SO}_4(\text{aq}) \rightarrow \text{BaSO}_4(\text{s}) + 2 \text{KNO}_3(\text{aq})
\]

A researcher adds 261 g sample of barium nitrate to 2.0 L of potassium sulfate solution in a polystyrene calorimeter. Complete the Analysis section of the lab report by calculating the molar enthalpy of reaction of barium nitrate.

\[
\Delta_r H_m = \frac{n}{n_m} \times \left( \frac{Q}{W} \right)
\]

Evidence

\[
T_1 = 26.0°C \quad T_2 = 29.1°C
\]

\[
\Delta_r H_m = \frac{n}{n_m} \times \left( \frac{Q}{W} \right) = \frac{n}{n_m} \times \left( \frac{(20000 \text{g})(4.18 \text{J/g°C})(29.1 - 26.0°C)}{261 \text{g}} \right) = -26 \text{kJ/mol}
\]

3) a) As an alternative to chemical energy, heating water is one of the most cost-effective uses of solar energy, providing hot water for showers, dishwashers, and washing machines. Determine the thermal energy acquired when the temperature of 100 L of water is raised from 6.5°C to 58.5°C.

\[
Q = mcA_f = (100000 \text{g})(4.18 \text{J/g°C})(58.5 - 6.5°C) = -21.8 \text{MJ}
\]

b) What mass of natural gas (methane) would have to be burned to heat the same volume of water by the same temperature change in part a)?

\[
\Delta H = 2nA_f H_m - 2nA_f H_m \quad \Rightarrow \quad n = \frac{m}{M} \quad \Rightarrow \quad m = nM
\]

\[
M = (8.15015576 \text{g mol}^{-1})(16.05 \text{kJ mol}^{-1}) = 435.76 \text{kJ}
\]

\[
\frac{\Delta_r H_m}{\Delta r H_m} = -802.5 \text{kJ/mol}
\]

\[
\frac{n}{n_m} = -21.8 \text{kJ} \quad \Rightarrow \quad n = \frac{m}{M} = \frac{802.5 \text{kJ}}{435.76 \text{kJ}}
\]

\[
= 1.84 \text{mol}
\]
4) The energy content of foods can be determined by combustion analysis using a calorimeter. The combustion of 1.25 g of peanut oil caused the temperature of 2.0 kg of water to increase by 5.3°C. Determine the energy content of peanut oil per gram.

\[
\Delta H = mc\Delta T = (2000 \text{g})(4.19 \frac{J}{\text{g} \cdot ^\circ \text{C}})(5.3 \text{°C}) = 44414.5 \text{ J}
\]

\[
\Delta H = \frac{44414.5}{1.25 \text{g}} = \frac{35531.2}{3} \text{ kJ/g}
\]

5) Calculate the standard enthalpy change for the following reaction using the following data.

\[
\text{Fe}_2\text{O}_3 (s) + 2 \text{Al} (s) \rightarrow \text{Al}_2\text{O}_3 (s) + 2 \text{Fe} (s)
\]

\[
\begin{align*}
\text{Given:} & \quad 4 \text{Al} (s) + 3 \text{O}_2 (g) \rightarrow 2\text{Al}_2\text{O}_3 (s) & \Delta H = -3351,4 \text{ kJ} \\
\text{Reverse} & \quad 2 \text{Fe} (s) + 3/2 \text{O}_2 (g) \rightarrow \text{Fe}_2\text{O}_3 (s) & \Delta H = -824,2 \text{ kJ}
\end{align*}
\]

\[
\begin{align*}
2 \text{Al} (s) + \frac{3}{2} \text{O}_2 (g) & \rightarrow \text{Al}_2\text{O}_3 (s) & \Delta H = -1675,7 \text{ kJ} \\
\text{Fe}_2\text{O}_3 (s) & \rightarrow 2 \text{Fe} (s) + \frac{3}{2} \text{O}_2 (g) & \Delta H = +824,2 \text{ kJ}
\end{align*}
\]

\[
\begin{align*}
2 \text{Al} (s) + \text{Fe}_2\text{O}_3 (s) & \rightarrow \text{Al}_2\text{O}_3 (s) + 2 \text{Fe} (s) \\
\Delta H & = -851,5 \text{ kJ}
\end{align*}
\]

6) Calculate the enthalpy for the oxidation of ethanol to acetic acid using the following data.

\[
3 \text{H}_2 (g) + \text{CO} (g) \rightarrow \text{CH}_4 (g) + \text{H}_2\text{O} (g)
\]

\[
\begin{align*}
\text{Given:} & \quad 2 \text{H}_2 (g) + \text{O}_2 (g) \rightarrow 2 \text{H}_2\text{O} (g) & \Delta H = ? -571,6 \text{ kJ} \\
\text{Reverse} & \quad 2 \text{C} (s) + \text{O}_2 (g) \rightarrow 2 \text{CO} (g) & \Delta H^0 = ? \\
\text{Reverse} & \quad \text{CH}_4 (g) + 2 \text{O}_2 (g) \rightarrow \text{CO}_2 (g) + 2 \text{H}_2\text{O} (g) & \Delta H^0 = -802,7 \text{ kJ} \\
\text{Reverse} & \quad \text{C}_6\text{H}_6 (s) \rightarrow 6 \text{C} (s) + 3/2 \text{O}_2 (g) & \Delta H = +110,5 \text{ kJ} \\
\text{Reverse} & \quad \text{CO}_2 (s) + 2 \text{H}_2\text{O} (s) \rightarrow \text{CH}_4 (s) + 2 \text{O}_2 (g) & \Delta H = +802,7 \text{ kJ} \\
\text{Reverse} & \quad \text{C} (s) + \text{O}_2 (s) \rightarrow \text{CO}_2 (s) & \Delta H = -393,5 \text{ kJ}
\end{align*}
\]

\[
\Delta H_{\text{Net}} = -725,4 \text{ kJ}
\]
7) Calculate the enthalpy for the oxidation of ethanol to acetic acid using the following data.

\[
\begin{align*}
H_2(g) + CO(g) + O_2(g) & \rightarrow CO_2(g) + H_2O(g) \\
\Delta H^0 &= -1650.6 \\
\Delta H &= -221.1 \\
\Delta H^0 &= -393.5
\end{align*}
\]

\[
\begin{align*}
2 C(s) + O_2(g) & \rightarrow 2 CO(g) \\
\Delta H^0 &= -221.1 \\
\Delta H &= ? \\
\Delta H^0 &= ?
\end{align*}
\]

\[
\begin{align*}
2 H_2(g) + O_2(g) & \rightarrow 2 H_2O(g) \\
\Delta H^0 &= -393.5 \\
\Delta H &= ? \\
\Delta H^0 &= ?
\end{align*}
\]

\[
\begin{align*}
C(s) + O_2(g) & \rightarrow CO_2(g) \\
\Delta H^0 &= ? \\
\Delta H &= ? \\
\Delta H^0 &= ?
\end{align*}
\]

\[
\begin{align*}
CO_2(g) & \rightarrow C(s) + O_2(g) \\
\Delta H &= +101.5 \\
\Delta H &= +43.9
\end{align*}
\]

\[
\begin{align*}
H_2O(l) & \rightarrow H_2O(g) \\
\Delta H &= +44.0 \\
\Delta H &= -393.5
\end{align*}
\]

\[
\begin{align*}
\text{CO}(g) + H_2(g) + O_2(g) & \rightarrow \text{H}_2\text{O}(g) + \text{CO}_2(g) \\
\Delta H &= -521.8
\end{align*}
\]

8) Cars and furnaces often do not run at their highest energy efficiency.

a) Calculate the molar enthalpy of complete combustion of propane.

Assume liquid water as one of the products.

\[
C_3H_8(s) + 5O_2(g) \rightarrow 4H_2O(l) + 3CO_2(g)
\]

\[
\Delta H = \sum n \Delta H_m - \sum n \Delta S \Delta T
\]

\[
= \sum (4 \text{ mol})(-285.8 \text{ kJ/mol}) + (6 \text{ mol})(-393.5 \text{ kJ/mol}) - \sum (1 \text{ mol})(-103.8 \text{ kJ/mol})
\]

\[
= -221.9 \text{ kJ}
\]

b) Calculate the molar enthalpy of complete combustion of propane.

Assume gaseous water as one of the products.

\[
C_3H_8(s) + 5O_2(g) \rightarrow 4H_2O(g) + 3CO_2(g)
\]

\[
\Delta H = \sum n \Delta H_m - \sum n \Delta S \Delta T
\]

\[
= \sum (4 \text{ mol})(-241.8 \text{ kJ/mol}) + (3 \text{ mol})(-393.5 \text{ kJ/mol}) - \sum (1 \text{ mol})(-103.8 \text{ kJ/mol})
\]

\[
= -2043.9 \text{ kJ}
\]

c) Calculate the molar enthalpy of incomplete combustion of propane using the following reaction.

\[
2C_3H_8(g) + 8O_2(g) \rightarrow C(s) + 2CO(g) + 3 CO_2(g) + 8 H_2O (g)
\]

\[
\Delta H = \sum n \Delta H_m - \sum n \Delta S \Delta T
\]

\[
= \sum (2 \text{ mol})(-103.8 \text{ kJ/mol}) + (3 \text{ mol})(-393.5 \text{ kJ/mol}) + (8 \text{ mol})(-241.8 \text{ kJ/mol}) - \sum (2 \text{ mol})(-103.8 \text{ kJ/mol})
\]

\[
= -3128.3 \text{ kJ}
\]

\[
= -156.4 \text{ kJ}
\]

d) List the above molar enthalpies of combustion of propane from lowest to highest.

\[
-2043.9 \text{ kJ/mol}, -221.9 \text{ kJ/mol}, -3128.3 \text{ kJ/mol}, -156.4 \text{ kJ/mol}
\]
9) Ammonium nitrate fertilizer is produced by the net reaction of ammonia with nitric acid. Ammonium nitrate is one of the most important fertilizers for increasing crop yields. **Calculate** the standard enthalpy change of the reaction.

\[
\Delta H = \sum n \Delta H_m \text{prod} - \sum n \Delta H_m \text{react}
\]

\[
= \sum (1\text{mol})(-366.6 \text{kJ/mol}) - \sum (1\text{mol})(-45.9 \text{kJ/mol})
\]

\[
= -145.6 \text{kJ}
\]

10) During World War II, an oil embargo on Germany left that country short of fuels. Germany responded by producing and burning ammonia as a fuel for cars, trucks, and tanks.

a) What is the standard molar enthalpy of combustion of ammonia gas?

**Assume liquid water as one of the products.**

\[
2 \text{NH}_3 (g) + \frac{3}{2} \text{O}_2 (g) \rightarrow 3 \text{H}_2\text{O}(l) + 2 \text{N}_2\text{O}_2 (g)
\]

\[
\Delta_r H = \sum n \Delta H_m \text{prod} - \sum n \Delta H_m \text{react}
\]

\[
= \sum (3\text{mol})(-285.8 \text{kJ/mol}) + (2\text{mol})(-45.9 \text{kJ/mol}) - \sum (2\text{mol})(-349.6 \text{kJ/mol})
\]

\[
= -699.2 \text{kJ/mol}
\]

b) **Draw** a completely labeled potential energy diagram for the above reaction.
11. Ethanoic acid (acetic acid) is an important industrial chemical that is manufactured from the reaction of methanol and carbon monoxide using rhodium or iridium catalysts.

a) Write a balanced chemical equation for the industrial production of ethanoic acid and determine the enthalpy change.

\[ \text{CH}_3\text{OH}(c\ell) + \text{CO}(g) \rightarrow \text{CH}_3\text{COOH}(c\ell) \]

\[ \Delta H = \sum n \Delta H_m - \sum n \Delta \tilde{H}_m \]

\[ = \left[ \sum (1 \text{ mol})(-484.3 \text{ kJ/mol}) \right] - \left[ \sum (1 \text{ mol})(-237.2 \text{ kJ/mol}) + (1 \text{ mol})(-10.5 \text{ kJ/mol}) \right] \]

\[ = -134.6 \text{ kJ} \]

b) Sketch a properly labeled chemical potential energy diagram and label the enthalpy change.

![Chemical potential energy diagram](image)

Production of ethanoic acid

\[ \Delta H = -134.6 \text{ kJ} \]

Run progresses

<table>
<thead>
<tr>
<th>E_p</th>
<th>(kJ)</th>
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<tbody>
<tr>
<td>484.3</td>
<td>-349.7</td>
<td>134.6</td>
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c) Sketch an energy pathway diagram, and label what the activation energies could look like for the uncatalyzed and catalyzed reactions.

![Energy pathway diagram](image)

Uncatalyzed

<table>
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catalyzed

d) Calculate the enthalpy of this reaction when 45.5 g if methanol is used.

\[ -191 \text{ kJ} \]