Enthalpy

Sample Problems:

1. Given the equation $3 \text{O}_2(g) \rightarrow 2 \text{O}_3(g) \, \Delta H = +285.4 \text{ kJ}$, calculate $\Delta H$ for the following reaction. $\frac{3}{2} \text{O}_2(g) \rightarrow \text{O}_3(g)$.

Answer
Since $\frac{3}{2} \text{O}_2(g) \rightarrow \text{O}_3(g)$ is $\frac{1}{2}$ of $3 \text{O}_2(g) \rightarrow 2 \text{O}_3(g)$ the enthalpy of the reaction will be $\frac{1}{2}$ as well: $\frac{1}{2} (+285.4 \text{kJ}) = +142.7 \text{kJ}$

2. Given the equation: $2 \text{Ag}_2\text{S(s)} + 2\text{H}_2\text{O(l)} \rightarrow 4\text{Ag(s)} + 2\text{H}_2\text{S(g)} + \text{O}_2(g) \, \Delta H = +595.5 \text{kJ}$, calculate $\Delta H$ for the following reaction.
$\text{Ag(s)} + \frac{1}{2} \text{H}_2\text{S(g)} + \frac{1}{4} \text{O}_2(g) \rightarrow \frac{1}{2} \text{Ag}_2\text{S(s)} + \frac{1}{2} \text{H}_2\text{O(l)}$

Answer
In this problem, the reaction equation has been reversed and divided by four. The new enthalpy value will be the opposite sign and $\frac{1}{4}$ its original value: $-\frac{1}{4}(+595.5 \text{kJ})$
$= -148.9 \text{kJ}$

3. Express the following information as a chemical equation. At $25^\circ\text{C}$ and at a constant pressure, dinitrogen trioxide gas decomposes to nitrogen monoxide and nitrogen dioxide gases with the absorption of $0.533 \text{kJ}$ of heat for every gram of dinitrogen trioxide that decomposes.
4. What is the enthalpy change when 12.8g H\(_2\) reacts with excess Cl\(_2\) to form HCl\(_g\)?

\[
\text{H}_2(g) + \text{Cl}_2(g) \rightarrow 2\text{HCl}(g) \quad \Delta H = -184.6 \text{kJ}
\]

Answer
12.8g H\(_2\) / 2.016g/mol = 6.35mol H\(_2\)
6.35mol H\(_2\) (-184.6kJ/mol H\(_2\)) = \(-1.17 \times 10^3\)kJ

5. What volume of CH\(_4\)\(_g\), measured at 25°C and 745Torr, must be burned in excess oxygen to release 1.00x10\(^6\)kJ of heat to the surroundings?

\[
\text{CH}_4(g) + 2\text{O}_2(g) \rightarrow \text{CO}_2(g) + 2\text{H}_2\text{O}(l) \quad \Delta H = -890.3 \text{kJ}
\]

Answer
There is 890.3kJ given off for every mole of CH\(_4\) burned, therefore the moles of CH\(_4\) needed are \(1.00 \times 10^6\)kJ/(890.3kJ/mol) = 1123mol CH\(_4\)

\[
V = \frac{nRT}{P} = \frac{(1123\,\text{mol})(.0821)(25^\circ\text{C} + 273.15)/(745/760)} = 2.80 \times 10^4 \text{L CH}_4
\]

Calorimetry

1. Calculate the heat capacity of a sample of brake fluid if the sample must absorb 911J of heat for its temperature to rise from 15°C to 100°C.

Answer
\[
C = \frac{q}{\Delta T} = \frac{911}{100-15} = 10.7 \text{J/}^\circ\text{C}
\]
2. A burner on an electric range has a heat capacity of 345J/K. What is the value of \( q \), in kilojoules, as the burner cools from a temperature of 467\(^\circ\)C to a room temperature of 23\(^\circ\)C?

**Answer**
\[
q = C \Delta T = (345 \text{J/K})(23-467) = -1.53 \times 10^5 \text{J} = -153 \text{kJ}
\]

**Molar Heat Capacity/Specific Heat**

1. How much heat, in calories and kilocalories, does it take to raise the temperature of 814g of water from 18.0\(^\circ\)C to 100\(^\circ\)C?

**Answer**
\[
q = mc \Delta T = (814 \text{g})(1 \text{cal/g}^\circ\text{C})(100^\circ\text{C} - 18^\circ\text{C}) = 6.67 \times 10^4 \text{cal} = 66.7 \text{Cal (kcal)}
\]

2. What mass of water, in kilograms, can be heated from 5.5\(^\circ\)C to 55.0\(^\circ\)C by 9.09 \times 10^{10} \text{J} of heat?

**Answer**
\[
m = \frac{q}{c \Delta T} = \frac{9.09 \times 10^{10} \text{J}}{(4.180 \text{J/g}^\circ\text{C})(55.0^\circ\text{C} - 5.5^\circ\text{C})} = 4.39 \times 10^8 \text{g} = 4.39 \times 10^5 \text{kg}
\]

3. A 454g block of lead is at an initial temperature of 22.5\(^\circ\)C. What will be the temperature of the lead after it absorbs 4.22kJ of heat from its surroundings?

**Answer**
\[
\Delta T = \frac{q}{mc} = \frac{4.22 \times 10^3 \text{J}}{(454 \text{g})(0.128 \text{J/g}^\circ\text{C})} = 72.6^\circ\text{C}
\]
Since heat is absorbed the temperature will go up
The final temperature is 22.5\(^\circ\)C + 72.6\(^\circ\)C = 95.1\(^\circ\)C
4. How many grams of copper can be heated from 22.5°C to 35.0°C by the same quantity of heat that can raise the temperature of 145g of H₂O from 22.5°C to 35.0°C?

**Answer**

\[(145g)(4.180\text{J/g°C}) = m(0.385\text{J/g°C})\]

1574.3g

1.57kg

**Bomb Calorimetry**

1. A 0.8082g sample of glucose (C₆H₁₂O₆) is burned in a bomb calorimeter assembly, and the temperature is noted to rise from 25.11°C to 27.21°C. Determine the heat capacity of the bomb calorimeter assembly, given:

\[
\text{C}_6\text{H}_{12}\text{O}_6(s) + 6\text{O}_2(g) \rightarrow 6\text{CO}_2(g) + 6\text{H}_2\text{O}(l)
\]

\[\Delta H = -2803\text{kJ}\]

**Answer**

moles of glucose = \[0.8082\text{g} / 180.2\text{g/mol} = 0.00449\text{mol}\]

\[q = -2803\text{kJ/mol} \times (0.00449\text{mol}) = -12.59\text{kJ}\]

\[C = q/\Delta T = 12.59\text{kJ}/2.10\text{°C} = 6.00\text{kJ/°C}\]

**Hess’s Law of Heat Summation**

1. Calculate the enthalpy change for the reaction

\[
\text{C}_2\text{H}_4(g) + \text{H}_2(g) \rightarrow \text{C}_2\text{H}_6(g) \quad \Delta H = ?
\]

Given:

\[
\text{C}_2\text{H}_4(g) + 3\text{O}_2(g) \rightarrow 2\text{CO}_2(g) + 2\text{H}_2\text{O}(l)
\]

\[\Delta H = -1410.9\text{kJ}\]

\[2\text{C}_2\text{H}_6(g) + 7\text{O}_2(g) \rightarrow 4\text{CO}_2(g) + 6\text{H}_2\text{O}(l)
\]

\[\Delta H = -3119.4\text{kJ}\]

\[2\text{H}_2(g) + \text{O}_2(g) \rightarrow 2\text{H}_2\text{O}(l)
\]

\[\Delta H = -571.6\text{kJ}\]
Answer:

\[ \text{C}_2\text{H}_4(\text{g}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) \]

\((4\text{CO}_2(\text{g}) + 6\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{C}_2\text{H}_6(\text{g}) + 7\text{O}_2(\text{g})) / 2 \) (flip equation and divide by 2)

\((2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{l})) / 2 \) (divide by 2)

\[ \text{C}_2\text{H}_4(\text{g}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) \quad \Delta H = -1410.9\text{kJ} \]

\[ 2\text{CO}_2(\text{g}) + 3\text{H}_2\text{O}(\text{l}) \rightarrow \text{C}_2\text{H}_6(\text{g}) + 7/2 \text{O}_2(\text{g}) \]  \( \Delta H = 1559.7\text{kJ} \)

\[ \text{H}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g}) \rightarrow \text{H}_2\text{O}(\text{l}) \]  \( \Delta H = -285.8\text{kJ} \)

Resulting Equation:

\[ \text{C}_2\text{H}_4(\text{g}) + \text{H}_2(\text{g}) \rightarrow \text{C}_2\text{H}_6(\text{g}) \quad \Delta H = -137.0\text{kJ} \]

Standard Enthalpy of Formation

1. Use data from table 6.2 (p257) to calculate \( \Delta H^\circ \) for the combustion of butane gas, \( \text{C}_4\text{H}_{10} \), to produce gaseous carbon dioxide and liquid water.

Answer:

\[ 2\text{C}_4\text{H}_{10}(\text{g}) + 13\text{O}_2(\text{g}) \rightarrow 8\text{CO}_2(\text{g}) + 10\text{H}_2\text{O}(\text{l}) \]

Using 

\[ \Delta H^\circ = \Sigma v_p \times \Delta H^\circ_{\text{f(products)}} - \Sigma v_r \times \Delta H^\circ_{\text{f(reactants)}} \]

\[ [10(-285.8\text{kJ/mol}) + 8(-393.5\text{kJ/mol})] – [2(-125.7\text{kJ/mol}) + 13(0\text{kJ/mol})] \]

\(-6006.0 – (-251.4) = \textbf{-5754.6kJ} \)

2. The combustion of thiophene, \( \text{C}_4\text{H}_4\text{S}(\text{l}) \), a compound used in the manufacture of pharmaceuticals, produces carbon dioxide and sulfur dioxide gases and liquid water. The enthalpy change in the combustion of one mole of \( \text{C}_4\text{H}_4\text{S}(\text{l}) \) is -2523kJ. Use this information and date from Table 6.2 to establish \( \Delta H^\circ_{\text{f}} \) for \( \text{C}_4\text{H}_4\text{S}(\text{l}) \).
**Answer:**

\[
\text{C}_4\text{H}_4\text{S}(_l) + 6\text{O}_2(_g) \rightarrow 4\text{CO}_2(_g) + \text{SO}_2(_g) + 2\text{H}_2\text{O}(_l) \quad \Delta H = -2523 \text{kJ}
\]

\[4(-393.5) + 1(-296.8) + 2(-285.8)] - [1(\Delta H) + 6(0)] = -2523

\[-2442.4 - \Delta H = -2523\]

\[\Delta H = 80.6 \text{kJ/mol}\]

**Ionic Reactions in Solution**

Given that \(\Delta H^\circ [\text{Mg(OH)}_2(_s)] = -924.5 \text{kJ/mol, what is the standard enthalpy change, } \Delta H^\circ,\)

for the reaction of aqueous solutions of magnesium chloride and potassium hydroxide? (Use table 6.3, p 261)

**Answer:**

\[
\text{MgCl}_2(_{aq}) + 2\text{KOH}(_{aq}) \rightarrow \text{Mg(OH)}_2(_s) + 2\text{KCl}(_{aq})
\]

\[
\text{Mg}^{2+}(_{aq}) + 2\text{OH}^-(_{aq}) \rightarrow \text{Mg(OH)}_2(_s)
\]

\[1(-924.5 \text{kJ})] - [1(-466.9 \text{kJ}) + 2(-230.0 \text{kJ})]

\[\Delta H^\circ = 2.4 \text{kJ per mole of } \text{Mg(OH)}_2(_s) \text{ formed}\]