6. Ex: If the burning of the fuel in a potato cannon performs 855 J of work on the potato and produces 1422 J of heat, what is $\Delta U$ for the burning of the fuel?

7. Ex: If a system has 30 J of heat added to it, and the total change in its internal energy is 10 J, how much work does it do?

\[ q = 30 \text{ J} \quad \Delta U = 10 \text{ J} \]

\[ \Delta U = q + w \]

\[ 10 \text{ J} = 30 \text{ J} + w \]

\[ w = -20 \text{ J} \]

\[ \rightarrow 20 \text{ J of work were done by the system} \]

8. Ex: Find the amount of work done on the surroundings when 1 liter of an ideal gas, initially at a pressure of 10 atm, is allowed to expand at constant temperature to 10 liters by a) reducing the external pressure to 1 atm in a single step, b) reducing P first to 5 atm, and then to 1 atm, c) allowing the gas to expand into an evacuated space so its total volume is 10 liters.
E. Coffee Cup Calorimeter Examples:

1. Ex: When 250.0 mL of 1.00 M NaOH is added to 250.0 mL of 1.00 M HCl already in a coffee cup calorimeter, the temperature of the solution increases from 23.4°C to 30.4°C. Determine the heat of reaction, \( \Delta H_{\text{rxn}} \).

2. Ex: The dissolving of \( \text{NH}_4\text{NO}_3 \) is used in chemical cold packs. If 27.07 g \( \text{NH}_4\text{NO}_3 \) is dissolved in 100.0 mL of water at 25.0°C, what is the final temperature of the solution?

\[
\text{NH}_4\text{NO}_3(s) \rightarrow \text{NH}_4^+(aq) + \text{NO}_3^-(aq)
\]

\( \Delta H_{\text{dissolving}} = 25.7 \text{ kJ/mol} \)

\[
Q_{\text{rxn}} = -Q_{\text{soln}}
\]

\( \Delta H_{\text{rxn}} \text{ (mol)} = -M_{\text{soln}} C_s, c_{\text{soln}} (T_f, \text{soln} - T_i, \text{soln}) \)

\[
(25.7 \text{ kJ/mol}) (0.338 \text{ mol}) = - (127.07 \text{ g})(4.184 \text{ J/g} \cdot \text{C})(T_f, \text{soln} - 25.0 \text{ C})
\]

\[
T_f, \text{soln} = 8.7 \text{ C}
\]

\[
\frac{27.07 \text{ g NH}_4\text{NO}_3}{1 \text{ mol NH}_4\text{NO}_3} = \frac{0.338 \text{ mol NH}_4\text{NO}_3}{80.05 \text{ g NH}_4\text{NO}_3}
\]
3. Ex: A 32.5-g cube of aluminum initially at 45.8 °C is submerged into 105.3 g of water at 15.4 °C. What is the final temperature of both substances at thermal equilibrium

\[
q_{Al} = -q_{w}
\]

\[(32.5\,\text{g Al})(0.903 \frac{\text{J}}{\text{g} \, ^\circ\text{C}})(T_f - 45.8^\circ \text{C}) = -(105.3\,\text{g})(4.184 \frac{\text{J}}{\text{g} \, ^\circ\text{C}})(T_f - 15.4^\circ \text{C})\]

\[29.3(T_f - 45.8^\circ \text{C}) = -441(T_f - 15.4^\circ \text{C})\]

\[29.3T_f - 1342 = -441T_f + 6791\]

\[470.3T_f = 8133\]

\[T_f = 17.3^\circ \text{C}\]

4. Ex: A hot piece of metal weighing 350.0 g is heated to 100.0 °C. It is then placed into a coffee cup calorimeter containing 160.0 g of water at 22.4 °C. The water warms and the copper cools until the final temperature is 35.2 °C. Calculate the specific heat of the metal and identify the metal.

\[q_{\text{metal}} = -q_{\text{water}}\]

\[(350.0\,\text{g})C_{s, \text{metal}}(35.2^\circ \text{C} - 100.0^\circ \text{C}) = -(160.0\,\text{g})(4.184 \frac{\text{J}}{\text{g} \, ^\circ\text{C}})\]

\[-22680C_{s, \text{metal}} = -8569\]

\[C_{s, \text{metal}} = 0.378 \frac{\text{J}}{\text{g} \, ^\circ\text{C}}\]

Copper!
C. \( \Delta H_{\text{rea}} \) values can be determined from \( \Delta H_f \) values.

This is the third way to determine \( \Delta H_{\text{rea}} \).

1. Table of \( \Delta H_f \) values on the conversion and equation sheet or online.

2. General formula:

\[
\Delta H_{\text{rea}} = \sum \text{(coeff)} \Delta H_{\text{rea}} (\text{products}) - \sum \text{(coeff)} \Delta H_{\text{rea}} (\text{reactants})
\]

3. Ex: Photosynthesis:

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

4. Ex: \( \text{CH}_4(g) + 2 \text{ O}_2(g) \rightarrow \text{CO}_2(g) + \text{H}_2\text{O}(g) \)

\[
\begin{array}{c|c|c|c}
\Delta H_f & \text{(kJ/mol)} \\
\hline
\text{CH}_4 & -73.4 \\
\text{O}_2 & 0 \\
\text{CO}_2 & -393.5 \\
\text{H}_2\text{O} & -241.8 \\
\end{array}
\]

\[
\Delta H_{\text{rxn}} = -393.5 + -241.8 - [(-73.4 + 2 \times 0)] = -561.9 \text{kJ/mol}
\]

5. Ex: \( 2 \text{C}_2\text{H}_2(g) + 5 \text{O}_2(g) \rightarrow 4 \text{CO}_2(g) + 2 \text{H}_2\text{O}(l) \)

\[
\begin{array}{c|c|c|c}
\Delta H_f & \text{(kJ/mol)} \\
\hline
\text{C}_2\text{H}_2 & 226.7 \\
\text{O}_2 & 0 \\
\text{CO}_2 & -393.5 \\
\text{H}_2\text{O} & -285.8 \\
\end{array}
\]

\[
\Delta H_{\text{rxn}} = 4(-393.5) + 5(-285.8) - [2 \times (226.7) + 5 \times 0] = -2599 \text{kJ/mol}
\]
VI. \( \Delta H_{rxn} \) and Stoichiometry

A. Ex: When 51.2 L of oxygen at 1 atm and 298 K are consumed in the burning of propane, how much heat energy is produced?

\[
C_3H_8(g) + 5 \text{O}_2(g) \rightarrow 3 \text{CO}_2(g) + 4 \text{H}_2\text{O}(g) \quad \Delta H_{rxn} = -2044 \text{kJ/mol}
\]

B. Ex: For the same reaction, how much energy is produced when 16.4 g of propane are burned?

\[
\frac{16.4 \text{g} \text{C}_3\text{H}_8}{44.09 \text{g} \text{C}_3\text{H}_8} = \frac{1 \text{mol} \text{C}_3\text{H}_8}{1 \text{mol} \text{C}_3\text{H}_8} = \frac{-2044 \text{kJ}}{1 \text{mol}} = -760 \text{kJ}
\]

C. Ex: Calculate the \( \Delta H_{rxn} \) for decomposing 10.0 g of limestone, CaCO\(_3\).

\[
\text{CaCO}_3(s) \rightarrow \text{CaO}(s) + \text{O}_2(g)
\]

<table>
<thead>
<tr>
<th>Material</th>
<th>( \Delta H^\circ ), kJ/mol</th>
</tr>
</thead>
<tbody>
<tr>
<td>\text{CaCO}_3(s)</td>
<td>-1207.6</td>
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<tr>
<td>\text{O}_2(g)</td>
<td>0</td>
</tr>
<tr>
<td>\text{CaO}(s)</td>
<td>-634.9</td>
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