Where do we get $10.2 \times 10^9$ J of energy?

$= 10.2 \text{ MJ}$

$= 1 \text{ year of HB.}$

HOT ROCKS - Very old School

Direct Energy Transfer.

OR. Stored Energy in Chemical Bonds.

$$\text{C}_\text{H}_4 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$$

$8 \text{kJ/ton}$

$$\text{LH}_2 + \text{O}_2 \rightarrow \text{CO}_2 + 2 \text{H}_2\text{O}$$

Combustion + heat.

$\Delta H_{\text{comb}} = 800 \text{ kJ/mole}$

OR $800 \text{ kJ/mole} \times \frac{16\text{g}}{1 \text{ mole}} = \frac{12800 \text{ kJ}}{16\text{g}} = 800 \text{ MJ/ton}$
\[
\frac{10.2 \text{ mJ}}{50 \text{ mJ/kg CHy}} = 0.2 \text{ kg CHy}
\]

or 12.7 moles of CHy

\[\Rightarrow 12.7 \text{ moles CO}_2\]

\[\Rightarrow 567 \text{ g } \approx \frac{1}{16} \text{ CO}_2\]

\[\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}\]

Is this reaction spontaneous?

Yes.

What about this reaction

\[\text{NaNO}_3 + \text{H}_2\text{O} \rightarrow \text{Na}^+ (aq) + \text{NO}_3^- (aq)\]

Let's do the reaction COLD.
So does heat alone describe the spontaneity of reactions? NO.

Second Law of Thermodynamics:

Spontaneous reactions increase the entropy of the Universe.

Examples: Big Bang.

\[ \Delta S_{\text{univ}} = \Delta S_{\text{system}} + \Delta S_{\text{surroundings}} \]

where \( S = k_B \ln W \)

\[ k_B = \text{Boltzmann constant} = 1.38 \times 10^{-23} \text{J/K} \]
So in our combustion of methane

3 moles of gas → mole of gas

$\Delta S_{\text{sys}}$ is small

however we did produce heat!!

\[
\Delta S_{\text{sum}} = \oint \frac{Q}{T} = \Delta H
\]

making thing move W↑

\[
\Delta S_{\text{uni}} = \Delta S_{\text{sys}} - \frac{\Delta H}{T}
\]

multiply everything by -T

\[
- T \Delta S_{\text{uni}} = \Delta H - T \Delta S_{\text{sys}}
\]

\[\Delta G = \Delta H - T \Delta S\]
Methane combustion is spontaneous because $\Delta H$ is negative.

$$\text{NaNO}_3 (s) \rightarrow \text{Na}^+ + \text{NO}_3^-$$

Is spontaneous because $\Delta G$ is negative.

$$\Delta G = \Delta H - T \Delta S$$

\text{Cold} \uparrow \quad \text{this must be big!}

\text{WEB}

$$\Delta G = U - TS + PV$$

6. Its free energy internal | Work on the System.

\text{from Surroundings}

$$\Delta G = \Delta H - T \Delta S$$

\uparrow \quad \text{the same thing}$$

$$\Delta U + \Delta PV$$
So we will come back to Gibbs free energy in a few lectures. For now we recognize that many spontaneous reactions produce heat.

\[ \text{C}_2\text{H}_4 + \text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} + \text{heat} \]

<table>
<thead>
<tr>
<th>( T )</th>
<th>Qn</th>
<th>Steam Engine</th>
<th>( - \text{work} )</th>
<th>Qc</th>
</tr>
</thead>
<tbody>
<tr>
<td>310</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bring to class

\[ Q_N = Q_c + \text{work} \]

\[ N = \frac{\text{Work}}{Q_{\text{in}}} = \frac{Q_{\text{out}} - Q_{\text{out}}}{Q_{\text{in}}} = 1 - \frac{Q_{\text{out}}}{Q_{\text{in}}} \]
Spontaneous reactions increase the entropy of the universe:

\[ \Delta S = \frac{Q}{T} \]

So go back to our drawing:

\[ \left( \frac{Q_h}{T} \right) \]

\[ Q_h \rightarrow \Delta S_h = \frac{Q_h}{T} \]

\[ \text{Engine} \]

\[ Q_c \rightarrow \Delta S_c = \frac{Q_c}{T} \]

\[ \frac{1}{T_c} \]

\[ \Delta S_e > \Delta S_h \]

\[ \frac{Q_e}{T_c} > \frac{Q_h}{T_n} \]

\[ T_c < \frac{Q_e}{T_c} \]

\[ T_c < \frac{Q_e}{Q_h} \]
\[ \eta = 1 - \frac{T_c}{T_h} \]

Using some #s: \( T_c = 300 \text{ K} \)

\[ T_h = 823 \text{ K} \]

\[ \eta \leq 1 - \frac{300}{823} = 0.64 \text{ or } 64\% \]

Another way of thinking about this:

\[ \left[ \begin{array}{c} T_h \\ Q_h = W + Q_c \\ \hline \end{array} \right] \]

Engine \( W \)

\[ \text{made this small: } Q_e \text{ small} \]

\[ \left[ \begin{array}{c} T_c \\ T_c \geq 0 \end{array} \right] \]

\[ \eta \leq 1 - \frac{0}{823} = 1 \]
Show Cannot Illustration.