In the video clip from George Gobel you saw that it is possible to light a charcoal grill in about a minute. If the grill is prepared using one 20 pound bag of charcoal (primarily carbon) and two 1 gallon buckets of liquid oxygen (the density of LOX (liquid oxygen) is 1142 kg/m³, CRC Handbook of Chemistry and Physics.)

1. Write a balanced chemical equation describing this reaction.

\[ \text{C(s)} + \text{O}_2 (i) \rightarrow \text{CO}_2 (g) \]

2. Determine the limiting reagent for this reaction.

amount of carbon

- \( \text{mass}\,\text{C} := 20\text{-lb} \)
- \( \text{mass}\,\text{C} = 9.07185 \cdot 10^3 \cdot \text{gm} \)
- \( \text{MW}\,\text{C} := 12.0107 \cdot \text{gm}\cdot\text{mole}^{-1} \)
- \( \text{mole}\,\text{C} := \frac{\text{mass}\,\text{C}}{\text{MW}\,\text{C}} \)
- \( \text{mole}\,\text{C} = 755.3138 \cdot \text{mole} \)

amount of oxygen

- \( V\,\text{O}_2 := 2\text{-gal} \)
- \( V\,\text{O}_2 = 7.57082 \cdot 10^3 \cdot \text{mL} \)
- \( \text{density}\,\text{O}_2 := 1142 \cdot \text{kg}\cdot\text{m}^{-3} \)
- \( \text{density}\,\text{O}_2 = 1.142 \cdot \text{gm}\cdot\text{mL}^{-1} \)
- \( \text{mass}\,\text{O}_2 := V\,\text{O}_2 \cdot \text{density}\,\text{O}_2 \)
- \( \text{mass}\,\text{O}_2 = 8.64588 \cdot 10^3 \cdot \text{gm} \)
- \( \text{MW}\,\text{O}_2 := 2 \cdot 15.9994 \cdot \text{gm}\cdot\text{mole}^{-1} \)
- \( \text{MW}\,\text{O}_2 = 31.9988 \cdot \text{gm}\cdot\text{mole}^{-1} \)
- \( \text{mole}\,\text{O}_2 := \frac{\text{mass}\,\text{O}_2}{\text{MW}\,\text{O}_2} \)
- \( \text{mole}\,\text{O}_2 = 270.1939 \cdot \text{mole} \)

Since the equation is balanced with a 1:1 stoichiometry for C and O₂, an equal number of moles are required. Since there are fewer moles of O₂, this is the limiting reagent.
3. Calculate the mass of each product and any remaining reactant.

\[ \text{mole } O_2_{\text{final}} : = \text{mole } O_2 - \text{mole } O_2 \]

\[ \text{mass } O_2_{\text{final}} : = \text{mole } O_2_{\text{final}} \times MW \text{ } O_2 \]

\[ \text{mole } C_{\text{final}} : = \text{mole } C - \text{mole } O_2 \]

\[ \text{mass } C_{\text{final}} : = \text{mole } C_{\text{final}} \times MW \text{ } C \]

\[ \text{mole } CO_2_{\text{final}} : = \text{mole } O_2 \]

\[ MW \text{ } CO_2 : = (12.0107 + 2 \times 15.9994) \text{ } gm \text{-} \text{mole}^{-1} \]

\[ \text{mass } CO_2 : = \text{mole } O_2 \times MW \text{ } CO_2 \]

4. Calculate the amount of heat released by this reaction.

\[ kJ : = 10^3 \text{ } \text{joule} \]

\[ \Delta H_{f_C} : = 0 \text{ } \text{kJ} \text{-} \text{mole}^{-1} \]

\[ \Delta H_{f_O2} : = -4.812 \text{ } \text{kJ} \text{-} \text{mole}^{-1} \]

\[ \Delta H_{f_{CO2}} : = -393.51 \text{ } \text{kJ} \text{-} \text{mole}^{-1} \]

\[ \Delta H_{rxn} : = \Delta H_{f_{CO2}} \text{-} \text{mole} - (\Delta H_{f_C} \text{-} \text{mole} + \Delta H_{f_O2} \text{-} \text{mole}) \]

\[ \Delta H_{rxn} = -388.698 \text{ } \text{kJ} \]

\[ \text{mole } rxn : = \text{mole } O_2 \]

\[ \Delta H : = \Delta H_{rxn} \times \text{mole } rxn \]

\[ \Delta H = -1.05024 \times 10^5 \text{ } \text{kJ} \]
5. If this heat is used to warm a 500 gallon tank of water at 15°C, what is the final temperature?

\[ E := -\Delta H \]
\[ V_{H_2O} := 500 \text{ gal} \]
\[ \text{density}_{H_2O} := 999.1026 \text{ kg m}^{-3} \]
\[ \text{mass}_{H_2O} := V_{H_2O} \times \text{density}_{H_2O} \]
\[ C_{H_2O,l} := 4.2 \text{ joule gm}^{-1} \text{ K}^{-1} \]

\[ E = \text{mass}_{H_2O} \times C_{H_2O,l} \times \Delta T \]
\[ \Delta T_{H_2O} := \frac{E}{\text{mass}_{H_2O} \times C_{H_2O,l}} \]
\[ \Delta T_{H_2O} = \frac{E}{\text{mass}_{H_2O} \times C_{H_2O,l}} = 13.22347 \text{ K} \]

\[ \Delta T = T_{\text{final}} - T_{\text{initial}} \]
\[ T_{\text{initial}_{H_2O}} := (273.15 + 15) \text{ K} \]
\[ T_{\text{final}_{H_2O}} := \Delta T_{H_2O} + T_{\text{initial}_{H_2O}} \]
\[ T_{\text{final}_{H_2O}} = 301.37347 \text{ K} \]

\[ T_{\text{final}_{H_2O}} - 273.15 = 28.22347 \]

6. If this heat is used to warm 40 kg of ice at 200 K, what is the final temperature?

Constants

\[ C_{H_2O,s} := 2.1 \text{ joule gm}^{-1} \text{ K}^{-1} \]
\[ C_{H_2O,g} := 2.0 \text{ joule gm}^{-1} \text{ K}^{-1} \]
\[ \Delta H_{\text{fusion}} := 333 \text{ joule gm}^{-1} \]
\[ \Delta H_{\text{vap}} := 2260 \text{ joule gm}^{-1} \]

First step, warm to 273.15 K

\[ \text{mass}_{H_2O} := 40 \text{ kg} \]
\[ \text{mass}_{H_2O} = 4 \times 10^4 \text{ gm} \]

\[ E_{\text{step}_1} = \text{mass}_{H_2O} \times (273.15 \text{ K} - 200 \text{ K}) \times C_{H_2O,s} \]
\[ E_{\text{step}_1} = 6.1446 \times 10^3 \text{ KJ} \]

\[ E_{\text{remain}} := E - E_{\text{step}_1} \]
\[ E_{\text{remain}} = 9.88792 \times 10^4 \text{ KJ} \]
Second step, melt ice

\[ E_{\text{step}_2} = \Delta H_{\text{fusion}} \cdot \text{mass} \, \text{H}_2\text{O} \]

\[ E_{\text{step}_2} = 1.332 \times 10^4 \, \text{kJ} \]

\[ E_{\text{remain}} = E - E_{\text{step}_1} - E_{\text{step}_2} \]

\[ E_{\text{remain}} = 8.5592 \times 10^4 \, \text{kJ} \]

Third step, heat liquid water

\[ E_{\text{step}_3} = \text{mass} \, \text{H}_2\text{O} \cdot (373.15 \, \text{K} - 273.15 \, \text{K}) \cdot C_{\text{H}_2\text{O}_l} \]

\[ E_{\text{step}_3} = 1.68 \times 10^4 \, \text{kJ} \]

\[ E_{\text{remain}} = E - E_{\text{step}_1} - E_{\text{step}_2} - E_{\text{step}_3} \]

\[ E_{\text{remain}} = 6.87592 \times 10^4 \, \text{kJ} \]

Fourth step, boil water

\[ E_{\text{step}_4} = \Delta H_{\text{vap}} \cdot \text{mass} \, \text{H}_2\text{O} \]

\[ E_{\text{step}_4} = 9.04 \times 10^4 \, \text{kJ} \]

\[ E_{\text{remain}} = E - E_{\text{step}_1} - E_{\text{step}_2} - E_{\text{step}_3} - E_{\text{step}_4} \]

\[ E_{\text{remain}} = -2.16408 \times 10^4 \, \text{kJ} \]

There is not sufficient energy available to boil all of the water, so only some of the water is converted into steam. The final temperature would be 100°C, or 373.15 K.

The mass of water that does boil is determined by the amount of energy available.

\[ \text{mass} \, \text{H}_2\text{O}_{\text{boil}} = \frac{E - E_{\text{step}_1} - E_{\text{step}_2} - E_{\text{step}_3}}{\Delta H_{\text{vap}}} \]

\[ \text{mass} \, \text{H}_2\text{O}_{\text{boil}} = 30.42444 \, \text{kg} \]