Energy of Chemical Transformations
When not enough $O_2$ is present, carbon monoxide is produced, and CO poisoning can occur:

$$C + O_2 \rightarrow CO$$

balanced equation

subscripts: # of atoms in a molecule
# in front = # of molecules in eqn.

$$2C + O_2 \rightarrow 2CO$$
Natural gas combustion: methane plus oxygen produces carbon dioxide plus water

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

_not balanced:_ 4 H’s on left and 2 H’s on right, 2O’s on left & 3 on right

Small amount of sulfur present in coal (it’s removed during petroleum refining)

\[ \text{S} + \text{O}_2 \rightarrow \text{SO}_2 \]

Burning to Balance Equations

Subscripts: # of atoms in a molecule

# in front indicates # molecules

2x2=4
Tips for Balancing Chemical Equations

What about burning gasoline?

Molecule + O\textsubscript{2} forms CO\textsubscript{2} + H\textsubscript{2}O

\[ \text{C}_8\text{H}_{18} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \quad \text{C}_8\text{H}_{18} + \text{O}_2 \rightarrow 8\text{CO}_2 + \text{H}_2\text{O} \]

\[ \text{C}_8\text{H}_{18} + \text{O}_2 \rightarrow 8\text{CO}_2 + 9\text{H}_2\text{O} \]

8x2+9 O’s on product side (25 O’s), leads to 12 \( \frac{1}{2} \) O\textsubscript{2} can’t have fractions

2\text{C}_8\text{H}_{18} + 25 \text{O}_2 \rightarrow 16\text{CO}_2 + 18\text{H}_2\text{O}

- If an element is present in just one compound on each side, balance it \textit{first}
- Balance anything that exists as a free element \textit{last}
- Balance polyatomic ions as a unit
- Check when done – same number of atoms, and same total charge (if any) on both sides

Burning propane?

\[ \text{C}_3\text{H}_8 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]
Chemical energy is in bonds between atoms. Energy is either released (exothermic) or consumed (endothermic) depending upon the strengths of the bonds in reactants and products.

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

Need to know the # and types of bonds in reactants and products.
Most atoms are reactive & react to form molecules with bonds between atoms—trying to achieve the same number of valence electrons as the noble gas of its period.

For our purposes, covalent bonds are pairs of shared electrons.

Structures that show the outer electrons are called **Lewis (dot) structures**

Lewis structures of atoms help us build molecular structures.

**example 1:** H• + •H → H:H → H-H

**example 2:** HF

\[ H^- + :F\rightarrow H:F\rightarrow H-F \]

H looks like He and F looks like Ne.

Line indicates a bond (pair of electrons).
Atoms will share some or all of their valence electrons to achieve the same electronic configuration as the noble gas in its period. Covalent bonds are formed from pairs of shared electrons, and each atom gets to count the bonding electrons as its own...

\[
\begin{align*}
O_2 & : \overset{\cdot}{O} + : \overset{\cdot}{O} \rightarrow \overset{\cdot}{O} : \overset{\cdot}{O} \Rightarrow \overset{\cdot}{O} = \overset{\cdot}{O} \\
H_2O & : \overset{\cdot}{O} + 2H: \rightarrow H: \overset{\cdot}{O} : H \Rightarrow H=O=H \Rightarrow \overset{\cdot}{O} : H
\end{align*}
\]

H looks like He and O looks like Ne
Chemical energy is in bonds between atoms. Energy is either released (exothermic) or consumed (endothermic) depending upon the strengths of the bonds in reactants and products.

Consider:

\[
2 \text{H-H} + \text{O=O} \rightarrow 2 \text{H-O-H}
\]

A mole of H-H bonds is 436 kJ (we have 2)
A mole of O=O bonds is 498 kJ

A mole of O-H bonds is 467 kJ (we have 2)

Reaction is exothermic by 498 kJ
Thermochemical Cycle for Combustion of Methane

Why burning methane makes sense (from an energy standpoint) to generate power:

\[
\begin{align*}
\text{H}_2\text{C} \quad \text{+ 2} \quad \text{O} = \text{O} & \quad \rightarrow \quad \text{O} = \text{C} = \text{O} \quad \text{+ 2} \quad \text{H} \cdot \text{O} \cdot \text{H} \\
\end{align*}
\]

A mole of C-H bonds is 416 kJ (we have 4)
A mole of O=O bonds is 498 kJ (we have 2)
A mole of O-H bonds is 467 kJ (we have 4)
A mole of C=O bonds is 803 kJ (we have 2)

“1 C + 4 H + 4 O”

- breaking 2 O=O bonds +996 kJ
- breaking 4 C-H bonds +1664 kJ
- making 2 C=O bonds -1606 kJ
- making 4 O-H bonds -1868 kJ
- exothermic

Hydrocarbons make good fuels because: O-H & C=O bonds are stronger than O=O, C-H, and C-C bonds.

### Table 4.2 Bond Energies (in kJ/mol)

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