Redox reactions release energy when electrons move ***closer*** to electronegative atoms

- Catabolic pathways ***relocate*** the electrons stored in food molecules
- This relocation of electrons *releases energy* that is used to make ATP
- Reactions that result in the ***transfer*** of one or more electrons from one reactant to another are oxidation-reduction reactions, or **redox reactions**.
  - The ***loss*** of electrons is called **oxidation.**
  - The ***addition*** of electrons is called **reduction.**
  - An example:
    - ***Cellular Respiration***:
    - $C_6H_{12}O_6 + 6 O_2 \rightarrow 6 CO_2 + 6 H_2O + ATP$
    - Glucose is ***OXIDIZED***; oxygen is ***REDUCED***
    - ***Photosynthesis:***
    - $6 CO_2 + 6 H_2O + \text{energy} \rightarrow C_6H_{12}O_6 + 6 O_2$
    - Carbon dioxide is ***REDUCED***; water is ***OXIDIZED***
- The formation of table salt from sodium and chloride is a redox reaction.

$$\mathbf{Na + Cl \rightarrow Na^{+} + Cl^{-}}$$

  - Here sodium, Na, is ***oxidized by chlorine***---it ***LOSES*** an electron…so its charge ***increases*** from 0 to +1. Chlorine is the oxidizing agent—it is oxidizing sodium.
  - Chlorine is ***reduced by sodium***---it ***GAINS*** an electron…so its charge ***drops*** from 0 to -1.
    Sodium is the reducing agent—it is reducing chlorine.

- More generally:

  - **$Xe^- + Y \rightarrow X + Ye^-$**

  - X, the electron donor, is the **reducing agent** and reduces Y (gives it an electron).

  - ***The electron donor (molecule that gives up an electron) is the reducing agent***

  - Y, the electron recipient, is the **oxidizing agent** and oxidizes X (takes an electron).

  - ***The electron recipient (molecule that receives an electron) is the oxidizing agent***

- Redox reactions require ***both a donor and acceptor***.

- Redox reactions also occur when the movement of electrons is ***not complete*** but involve a ***change in the degree of electron sharing in covalent bonds (electronegativity).***

- In the combustion (burning) of methane to form water and carbon dioxide, the nonpolar covalent bonds of methane (C-H) and oxygen (O=O) are converted to polar covalent bonds (C=O and O-H).

- When these bonds shift from non polar to polar, the electrons move from positions equidistant between the two atoms to a ***closer position to oxygen***, the more *electronegative* atom.

  - Oxygen is one of the ***most potent oxidizing agents*** (electrons just LOVE to be close to oxygen ☺)

- An electron ***loses energy*** when it shifts from a less electronegative atom to a more electronegative one.

- A redox reaction that relocates electrons closer to oxygen releases chemical energy that can do work.

- To reverse the process, energy must be added to pull an electron away from an atom.

Electrons "fall" from organic molecules to oxygen during cellular respiration

- In cellular respiration, glucose and other fuel molecules are oxidized (they lose electrons), therefore ***releasing energy***.
- In the summary equation of cellular respiration:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

- Glucose is oxidized (loses electrons), oxygen is reduced (gains electrons)
- This transfer of electrons releases some potential (stored) energy in the process---ENERGY THAT IS NOW AVAILABLE TO DO WORK!
- ***By oxidizing glucose, cellular respiration takes energy out of storage and makes it available for ATP synthesis***
- Molecules that have ***lots of hydrogen*** are excellent fuels because their bonds are a source of "hilltop" electrons that "fall" closer to oxygen.
- The cell has a rich reservoir of electrons associated with hydrogen, especially in carbohydrates and fats (*think about how many H atoms are in these molecules).*
- However, these fuels do not spontaneously combine with O_2 because they lack the activation energy.
- Enzymes lower the barrier of activation energy, allowing these fuels to be oxidized slowly, through many "small steps".

The "fall" of electrons during respiration is ***STEPWISE***, via NAD^+ and an electron transport chain

- Cellular respiration does not oxidize glucose in a single step that transfers all the hydrogen in the fuel to oxygen at one time *(Why would releasing this in a single step be a bad idea??)*
- $$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$
- Rather, glucose and other fuels are broken down *gradually* in a ***series of steps***, each catalyzed by a ***specific enzyme.***
- At key steps, hydrogen atoms are taken from glucose and passed first to a ***coenzyme***, like **NAD^+** (nicotinamide adenine dinucleotide).

- Dehydrogenase enzymes strip two hydrogen atoms from the fuel (e.g., glucose)…. H, H (each with 1 proton and 1 electron)

- Passes ***two*** electrons and ***one proton*** to NAD^+ …H (with one proton and 1 electron) and 1 electron from the other H

- and the other proton is released as H^+.

- H-C-OH + NAD^+ ➔ C=O + NADH + H^+

- This changes the oxidized form, NAD+, to the reduced form NADH.
  - NAD+ functions as the oxidizing agent in many of the redox steps during the catabolism (breakdown) of glucose.

- The electrons carried by NADH lose very little of their potential energy in this process.

- This energy is tapped to synthesize (build) ATP as electrons "fall" from NADH to oxygen.

- Unlike the explosive release of heat energy that would occur when H_2 and O_2 combine, cellular respiration uses an **electron transport chain** to break the fall of electrons to O_2 into several steps.

- The electron transport chain, consisting of several molecules (primarily proteins), is built into the inner membrane of a mitochondrion.

- NADH shuttles electrons from food to the "top" of the chain.

- At the "bottom", oxygen captures the electrons and H^+ to form water.

- The free energy change from "top" to "bottom" is -53 kcal/mole of NADH.

- Electrons are passed by increasingly more electronegative molecules in the chain until they are caught by oxygen, the most electronegative.