I ♥ Energy
Cellular Respiration (Glycolysis, Krebs' Cycle, etc)

Where Is the Energy in Food?

- The energy for living is obtained by breaking down the organic molecules originally produced in plants
  - the ATP energy and reducing power invested in building the organic molecules are stripped away as the chemical bonds are broken and used to make ATP
  - the oxidation of food stuffs to obtain energy is called **cellular respiration**

- The process of aerobic respiration requires oxygen and carbohydrates

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

- The products are carbon dioxide, water, and energy (heat or ATP)

- Cellular respiration takes place in two stages
  1. **Glycolysis**
     - occurs in the cytoplasm
     - does not require oxygen to generate ATP
  2. **Krebs cycle**
     - occurs within the mitochondrion
     - harvests energy-rich electrons through a cycle of oxidation reactions
     - the electrons are passed to an electron transport chain in order to power the production of ATP

An overview of aerobic respiration

Using Coupled Reactions to Make ATP

- Glycolysis is a sequence of reactions that form a **biochemical pathway**

  - in ten enzyme-catalyzed reactions, the six-carbon sugar glucose is broken into two three-carbon pyruvate molecules

  - the breaking of the bond yields energy that is used to phosphorylate ADP to ATP
    - this process is called **substrate-level phosphorylation**
    - in addition, electrons and hydrogen are donated to NAD+ to form NADH

How glycolysis works

The reactions of glycolysis

- Glycolysis yields only a small amount of ATP
  - only two ATP are made for each molecule of glucose

- this is the only way organisms can derive energy from food in the absence of oxygen
- all organisms are capable of carrying out glycolysis
- this biochemical process was probably one of the earliest to evolve

- Some organisms can still perform, after glycolysis, oxidation reactions to make ATP even in the absence of oxygen
  - these organisms perform **anaerobic respiration**
    - the process involves using an electron acceptor other than oxygen

- Many organisms use sulfur, nitrate, or other inorganic compounds as the electron acceptor in place of oxygen during anaerobic respiration
  - **methanogens**
    - primitive archaea use CO_2 as the electron acceptor in addition to hydrogens derived from organic molecules
    - this process reduces CO_2 to CH_4 (methane)
  - **sulfur bacteria**
    - certain primitive bacteria can use inorganic sulfate (SO_4) as an electron acceptor and form hydrogen sulfide (H_2S)

- In the absence of oxygen, animals and plants recycle NAD+ add the glycolysis-extracted electron in NADH to an organic compound
  - this process is called **fermentation**
    - animals, such as ourselves, add electrons to pyruvate and form **lactate**
    - yeasts (single-celled fungi) first convert pyruvate into acetaldehyde and then add the extracted electron to form **ethanol**

Two types of fermentation

Harvesting Electrons from Chemical Bonds

- In the presence of oxygen, the first step of oxidative respiration in the mitochondrion is the oxidation of pyruvate
  - pyruvate still contains considerable stored energy at the end of glycolysis
  - the first step is to oxidize pyruvate to form acetyl-CoA

- When pyruvate is oxidized, a single of its three carbons is cleaved off by the enzyme **pyruvate dehydrogenase**
  - this carbon leaves as part of a CO_2 molecule
  - in addition, a hydrogen and electrons are removed from pyruvate and donated to NAD+ to form NADH
  - the remaining two-carbon fragment of pyruvate is joined to a cofactor called coenzyme A (CoA)
  - the final compound is called **acetyl-CoA**

Producing acetyl-CoA

- The fate of acetyl-CoA depends on the availability of ATP in the cell
  - if there is insufficient ATP, then the acetyl-CoA heads to the Krebs cycle
  - If there is plentiful ATP, then the acetyl-CoA is diverted to fat synthesis for energy storage

- The Krebs cycle is a series of nine reactions that can be broken down into three stages of oxidative respiration
  1. Acetyl-CoA enters the cycle and binds to a four-carbon molecule, forming a six-carbon molecule
  2. Two carbons are removed as CO_2 and their electrons donated to NAD^+. In addition, an ATP is produced.
  3. The four-carbon molecule is recycled and more electrons are extracted, forming NADH and $FADH_2$.

How the Krebs cycle works

The Krebs cycle

- In the process of cellular respiration, the glucose is entirely consumed
  - the energy from its chemical bonds has been transformed into
    - four ATP molecules
    - 10 NADH electron carriers
    - 2 FADH2 electron carriers

Using the Electrons to Make ATP

- Mitochondria use chemiosmosis to make ATP
  - first proton pump use energetic electrons extracted from food molecules to pump protons across the cristae
  - as the concentration of protons builds up in the intermembrane space, the protons re-enter the matrix via ATP synthase channels
  - their passage powers the production of ATP from ADP

- NADH and $FADH_2$ transfer their electrons to a series of membrane-associated molecules called the **electron transport chain**
  - the transport pass along the electrons to each other and act as proton pumps
  - the last transport protein donates the electrons to hydrogen and oxygen in order to form water

The electron transport chain

- Chemiosmosis is integrated with electron transport
  - electrons harvested from reduced carriers (NADH and FADH2) are used to drive proton pumps and concentrate protons in the intermembrane space
  - the re-entry of the protons into the matrix across ATP synthase drives the synthesis

of ATP by chemiosmosis

An overview of the electron transport chain and chemiosmosis

Glucose Is Not the Only Food Molecule

- Cells also get energy from foods other than sugars
- The other organic building blocks undergo chemical modifications that permit them to enter cellular respiration