Energetics and Catabolism
Building the Environment

- Sun is ultimate energy source
- Photosynthesis
  - Captures light, stores as chemical energy
- Heterotrophy
  - Uses captured chemical energy
  - Builds other chemicals
- Waste
  - Each step gives off heat energy
Building the Cell

- **Catabolism**
  - Breaking down molecules for energy

- **Anabolism**
  - Using energy to build cell components
  - Reducing entropy, creating order

- **Metabolism**
  - Balance between catabolism and anabolism
  - Central biochemical pathways used for both
    - TCA cycle, glycolysis, pentose phosphate shunt
Building the Cell

- Predominant energy source is electricity
  - Electrons passed from A to B
    - A is oxidized, B is reduced
    - Energy of electron flow powers the cell

- Photosynthesis
  - Light reduces electron donors

- Heterotrophy
  - Reduced compounds used for energy

- Energy used to build cell components
Electron Transfer

- Major source of cell energy
  - Passage of electrons releases energy
    - Requires electron donor, electron acceptor

- Electron transport found in all cells
  - Different donors, acceptors

- Electron energy can be stored
  - Reduced chemicals
  - Concentration gradient
  - Phosphorylation of chemicals
Phosphorylation Energy

- Less energy than oxido-reduction
  - Useful energy level for most cell reactions
- No electron donor or acceptor needed
- Phosphate added via dehydration
  - Released via hydrolysis
    - Water is plentiful
- ATP most common
  - GTP sometimes is present

\[
\text{ADP} + \text{HOPO}_3^- + \text{H}^+ \rightarrow \text{ATP} + \text{H}_2\text{O} \quad \Delta G^\circ = 31 \text{ kJ/mol}
\]
Metabolism

Sunlight
(Major energy source today)

Phototrophy

Reduced geological compounds (rocks, inorganic compounds)
(First energy source)

Lithotrophy

(Reduced) biological macromolecules (starch, fats)
(Energy source for animals)

Organotrophy

Energy

CATABOLISM

Short-term energy storage

ATP

Long-term energy storage

Biosynthesis

ANABOLISM

Carbon, nitrogen, water

Microbiology: An Evolving Science
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Enzymes Catalyze Reactions

- Reactions don’t always occur
  - Even if $\Delta G < 0$
  - Kinetic barrier
    - Activation energy
- Enzymes = catalysts
  - Lower activation energy
    - Remove kinetic barrier
  - Allow reaction to occur rapidly
Catabolism: The Microbial Buffet

Microbes have great catabolic diversity

- **Electron donors**
  - Lithotrophy: inorganic molecules
  - Organotrophy: organic molecules
  - Phototrophy: use light energy to reduce compounds, then use these as electron donor

- **Electron acceptors**
  - Respiration: inorganic molecules
  - Fermentation: organic molecules
Organotrophy

- Wide range of organic compounds digested
  - Polysaccharides
    - Converted to glucose
  - Lipids
    - Converted to acetyl-CoA
      - And glycerol
  - Amino acids
  - Aromatic compounds
    - Converted to acetyl-CoA
Glucose Breakdown

- ** Glycolysis
  - Embden-Meyerhof-Parnas pathway
  - Glucose is activated
    - Phosphorylated twice by ATP
  - Activated phospho-sugar is split
    - Converted to glyceraldehyde 3-phosphate
  - Glyceraldehyde-3-P is oxidized
    - Energy stored as ATP
    - End product is 2 pyruvates
  - Requires 2 ATP, yields 4 ATP
    - + 2 NADH
Glucose Breakdown

- **Entner-Doudoroff Pathway**
  - Used by *E. coli*
  - Glucose or sugar acid is activated
    - Phosphorylated once by ATP
  - Glucose-6-P is oxidized, then split
    - Converted to 6-P-gluconolactone
      - Then to pyruvate and glyceraldehyde-3-P
  - Glyceraldehyde-3-P is oxidized
    - as in EMP pathway
  - Requires 1 ATP, yields 2 ATP
    - + 1 NADH, 1 NADPH
Glucose Breakdown

- Pentose phosphate shunt
  - Glucose is activated
    - Phosphorylated once by ATP
  - Glucose-6-P is oxidized twice
    - Converted to 6-P-gluconolactone
    - Oxidized to ribulose-5-P
  - Ribulose-5-P is used for biosynthesis
    - Produces ribose for nucleic acids
  - Requires 1 ATP, yields 2 ATP
    - + 2 NADPH
The Tricarboxylic Acid Cycle

- **Respiration**
  - Need to eliminate pyruvate
  - Oxidize completely to CO$_2$
    - Only possible with inorganic electron acceptor
    - Respiration produces more energy than fermentation
    - Fermentation only when no inorganic acceptor present

- **Pyruvate dehydrogenase complex**
  - Converts pyruvate to acetyl-CoA
    - CO$_2$ diffuses easily out of cell
    - Electrons passed to NADH
The TCA Cycle

- Eliminates Pyruvate/AcetylCoA
  - Oxidize completely to CO$_2$
    - Pyruvate = glycolysis product
    - AcCoA = lipid oxidation product
  - Make ATP
- Need oxaloacetate
  - Add 2C to 4C → 6C
  - Oxidize twice
    - Eliminate 2C, make ATP
  - Produce 4C compound
    - Succinate
Advantage of Cycles

- Pathway requires source
  - Oxaloacetate must be supplied
- Pathway builds up products
  - Succinate is produced
- Convert product to source
  - Solves both problems
    - Always have source reagent
    - Never build up product excess
- Many cycles in biology
The TCA Cycle

- Coenzyme A carries away $\text{CO}_2$
  - While oxidizing the molecule
  - Used 3 times for oxidation of pyruvate
- TCA intermediates used throughout cell
  - Form amino acids
    - Oxaloacetate, $\alpha$-ketoglutarate
      - TCA used for catabolism and anabolism
- Variant cycles used in some microbes
  - Glyoxylate cycle
Fermentation

- Glucose is oxidized
  - NADH is reduced
    - Must be reoxidized to NAD$^+$ + H$^+$
  - Pyruvate product builds up
    - Must be eliminated

- Fermentation
  - Pass electrons back to pyruvate
    - Or to Acetyl-CoA produced from pyruvate
  - Convert pyruvate into other products
    - Useful for cell, or easy to eliminate
Fermentation

- **S. cerevisiae** (baker’s yeast)
  - Decarboxylate pyruvate
    - \( \text{CO}_2 \) produced causes bread to rise
  - Reduce acetaldehyde to ethanol
- Vertebrate muscles
  - Lactate buildup, reoxidized when \( \text{O}_2 \) present
- **E. coli**
  - Mixed fermentation produces formate, acetate
- **Propionibacterium**
  - \( \text{CO}_2 \) produced makes holes in cheese
Aromatic Catabolism

- Bacteria can degrade many compounds
  - *Pseudomonas, Rhodococcus*
- Aromatic compounds converted to pyruvate
  - Allows growth in wide range of environments
  - Used for bioremediation
    - Cleaning up oil spills
    - Cleaning industrial sites
    - Degrading toxic compounds
Gibbs Free Energy

- \( \Delta G = \Delta H - T \Delta S \)
  - \( \Delta H \) = change in enthalpy
    - Release of heat
  - \( \Delta S \) = change of entropy

- \( \Delta G \) must be negative for reaction to occur
  - Reaction can be blocked even if \( \Delta G < 0 \)

- \( \Delta G \) depends on reactant concentration
  - \( \Delta G = \Delta G^\circ + RT \ln \frac{[C][D]}{[A][B]} \)
    - Low product concentration can drive reaction
Biochemical Reaction Energy

- $\Delta G = \Delta H - T\Delta S$
- Entropy stronger at higher temperatures
  - Breakdown of a large molecule into small ones
  - Release of gas
- Diffusion spreads molecules out
  - Requires energy to contain them
- Gradient = stored energy