Chemistry 506: Allied Health Chemistry 2

Chapter 20: Bioenergetics

Energy Generation in the Cell

Introduction to General, Organic & Biochemistry, 5th Edition by Bettelheim and March: Chapter 20, Pages 641-664

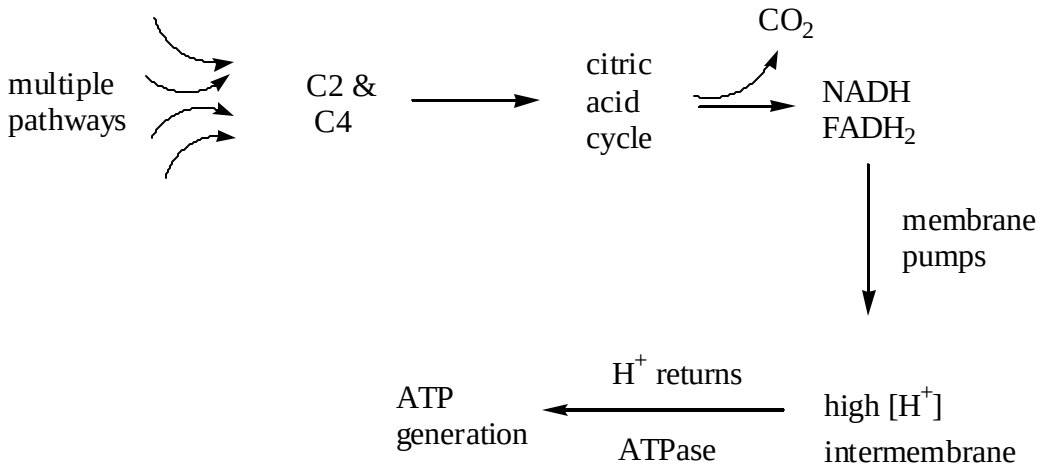
Outline Notes by Dr. Allen D. Hunter, YSU Department of Chemistry, ©2000.

Outline

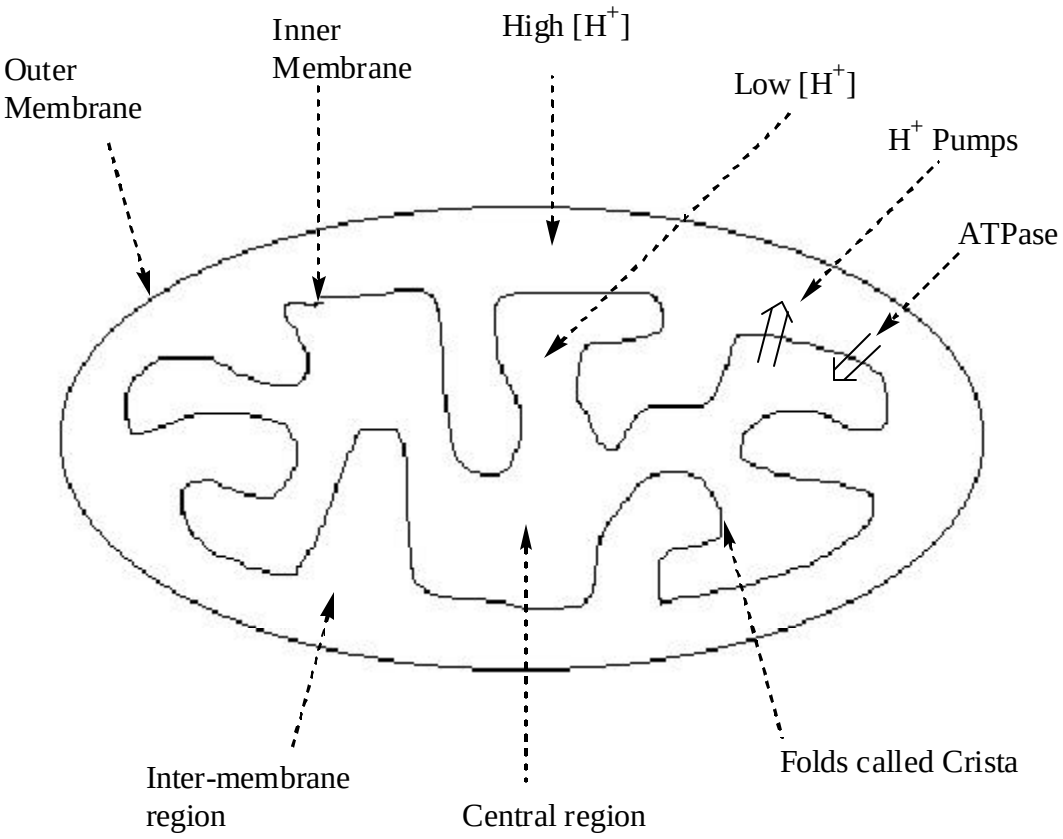
1A Section(s) 20.1/2 Introduction & Mitochondria

- Metabolism
  - All of the chemical reactions in a cell
  - Catabolism
    - The chemical reactions in the cell that break complex molecules down
  - Anabolism
    - The chemical reaction in the cell that build complex molecules
  - Complexity
    - Thousands of interrelated compounds, reactions, and enzymes
    - All under detailed feedback and control
    - Ultimately governed by the DNA and the cell's responses to the environment

- Energy Generation in the Cell
  - General Process
  - Overall Catabolic Pathway
    - Figure 20.1 on page 643



- Structure of Mitochondrion
  - Figures 20.2 and 20.3 on pages 644 and 645

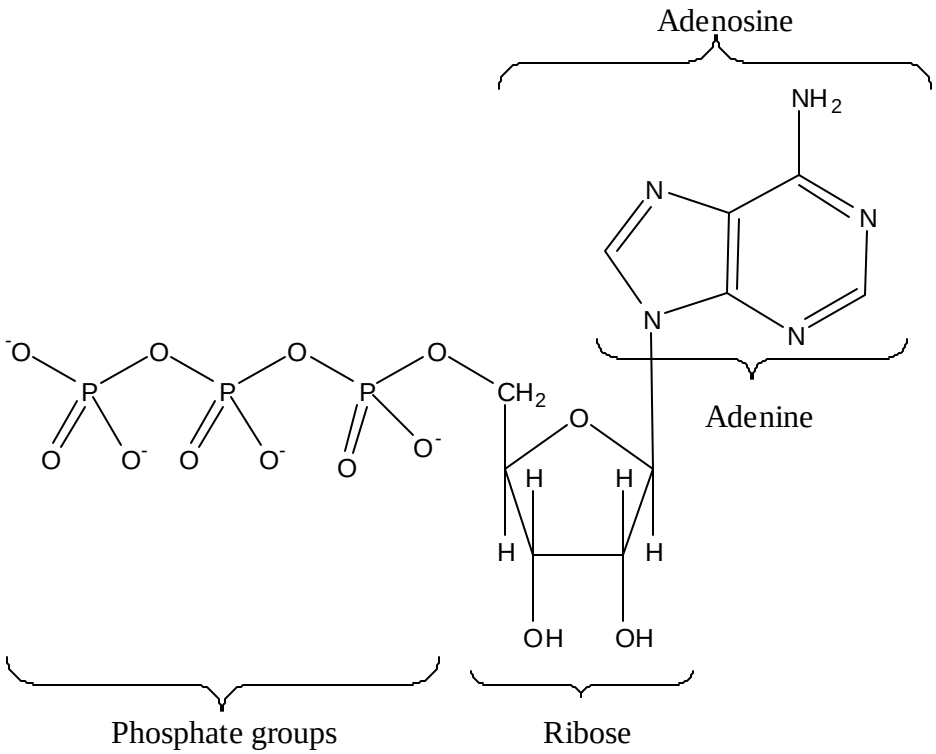


- Summary of Process
  - Multiple "food" molecules get converted into a small number of common C2 and C4 molecules
  - These C2/C4 molecules enter the center of the mitochondria where they are "processed" by the citric acid pathway
  - The citric acid pathway gives H^+ and e^- which are used to generate NADH and $FADH_2$
    - These are e^-, H^+, and energy carrier molecules
  - These are used by proteins on the inner mitochondrial membrane to pump H^+ ions from the center to the inter-membrane region
    - This gives a proton gradient
      - This proton gradient drives protein reactions on the inner membrane which allow them back into the center of the mitochondrion which simultaneously using their energy to generate ATP from ADP

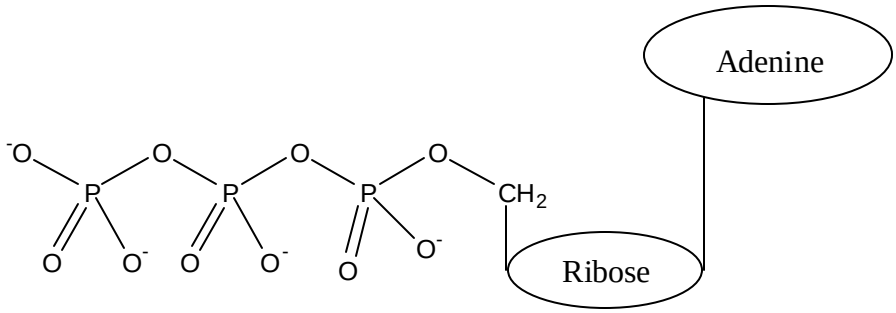
1B Section(s) 20.3 Common Catabolic Molecules

- P_i-AMP-ADP-ATP Path
  - Inorganic Phosphate, P_i, $H_2PO_4^-$ (charge depends on pH)
  - Adenosine Monophosphate, AMP
  - Adenosine Diphosphate, ADP
  - Adenosine Triphosphate, ATP
    - ATP is the highest energy

- Structure of ATP Molecule
  - Page 646 of the text
  - Adenine, Ribose, Adenosine, and Phosphate moieties
  - ADP and AMP structures



- Phosphate Bonds
  - ATP is "energy currency" of the cell
  - "high energy bonds" vs. convertible energy



- Hydrolysis
  - Hydrolysis of ATP

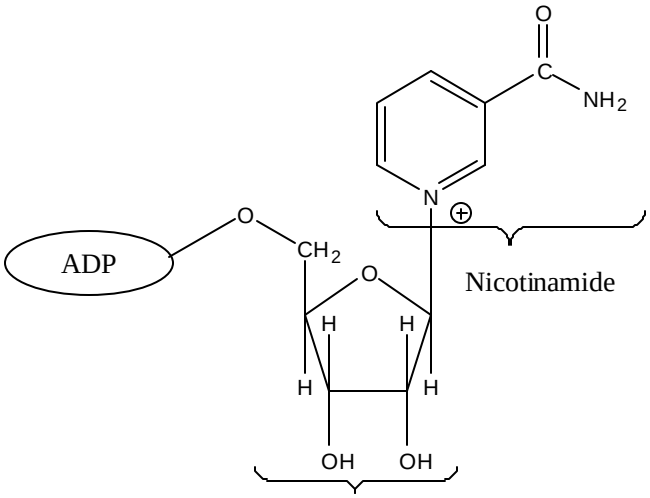
$$ATP + H_2O \rightarrow ADP + P_i + \text{Energy}$$

  - Hydrolysis of ADP

$$ADP + H_2O \rightarrow AMP + P_i + \text{Energy}$$

  - Normally ADP not hydrolyzed by cells

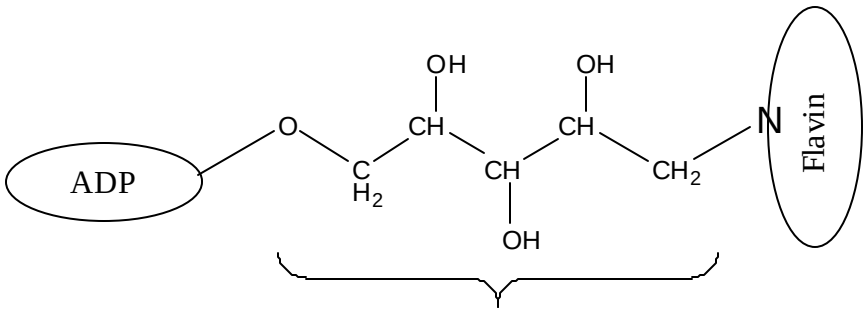
- Nicotinamide Adenine Dinucleotide, NAD
  - Figure 20.6 on page 648
  - Often Referred to as NAD^+ to reflect the charge on the Nicotinamide base
  - Is a Coenzyme
  - Contains ADP, Ribose, and a Nicotinamide Base



$$NAD^+ + H^+ + 2e^- \rightarrow NADH$$

- Thus NADH carries $2e^-$, a proton, and energy to where it is needed

- Flavin Adenine Dinucleotide, FAD
  - Figure 20.6 on page 648
  - Is a Coenzyme
  - Contains ADP, Ribitol (a straight chain sugar), and Flavin
    - The latter two groups making up Riboflavin (the vitamin)



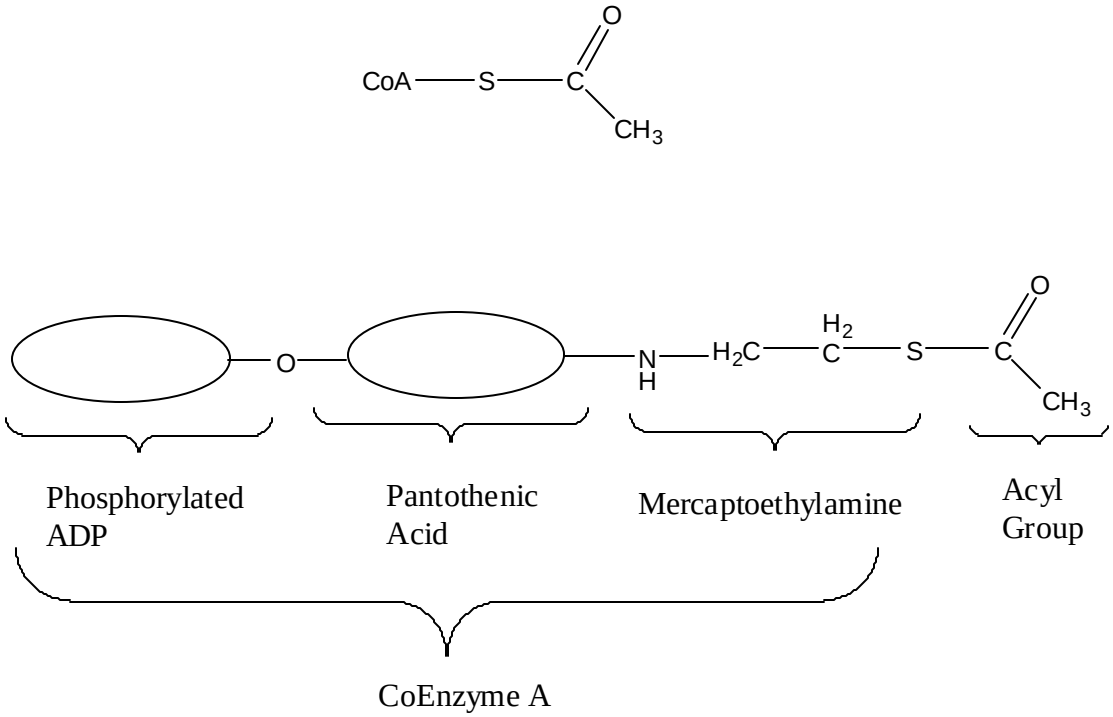
Ribitol

Riboflavin

$$FAD + 2H^+ + 2e^- \rightarrow FADH_2$$

- Thus $FADH_2$ carries $2e^-$, two protons, and energy to where it is needed

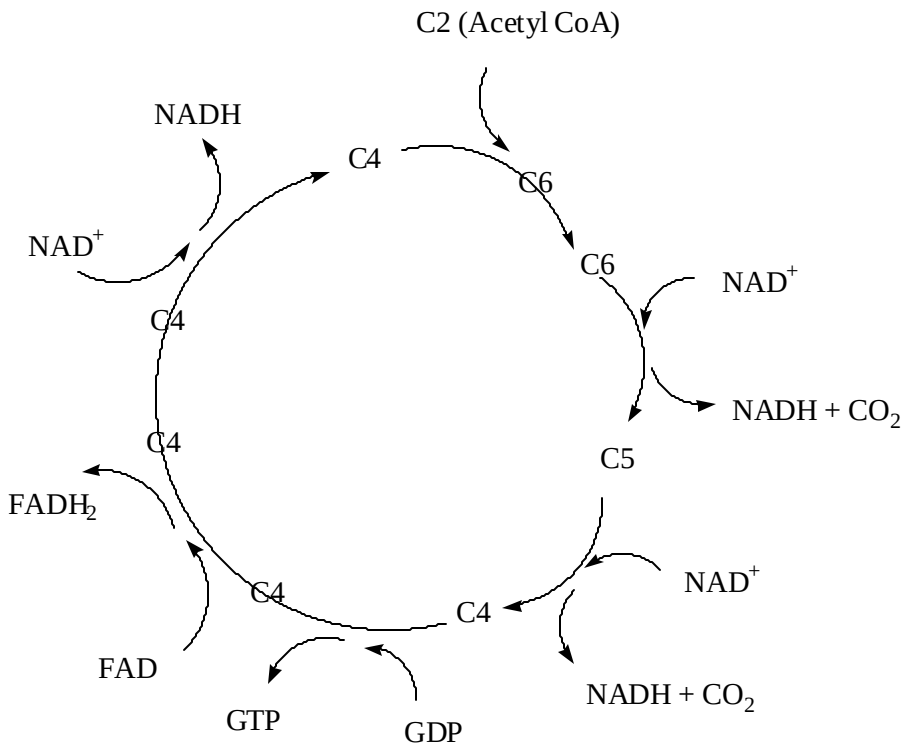
- Acetyl CoA
  - Figure 20.7 on page 649
  - Transports C2 units (acyl groups)
    - Often written as CH_3-CO-S-CoA or Acyl-CoA



- Notice the overall similarity in the structures of ATP, NADH, $FADH_2$, and Acetyl CoA

1C Section(s) 20.4 Citric Acid Cycle

- Also known as Krebs Cycle and Tricarboxylic Acid Cycle
- Figure 20.8 on page 650
- Overall Molecular Flow
  - 8 different chemicals
  - 8 different sets of enzymes
  - Takes place in the center of the mitochondrion
  - C2 fragments enter the cycle as Acetyl CoA



- Overall Energy Flow
  - Produces two CO_2, three NADH, one $FADH_2$, and one GTP per cycle
    - GTP is Guanidine Triphosphate (ATP like)

$$3\ \text{NADH} \Rightarrow 9\ \text{ATP}$$

$$1\ \text{FADH}_2 \Rightarrow 2\ \text{ATP}$$

$$1\ \text{GTP} \approx 1\ \text{ATP}$$

Thus: Acetyl Co A $\Rightarrow$ 12 ATP

1D Section(s) 20.5/6/7 ATP Synthesis

- Proton Pumps
  - Flavo Protein, FeS Protein, Quinone Enzyme Complex
  - Sited on the inner mitochondrial membrane
  - Use NADH and $FADH_2$ to pump H^+ into the inter-membrane space
  - This generates the proton gradient

- ATPase
  - An enzyme on the inner mitochondrial membrane
  - Allows H^+ to flow back into the central membrane cavity
  - H^+ flow mechanically coupled to ATP generation

$$ADP + P_i \text{ (ATPase)} \rightarrow ATP$$

- Net Results

Each NADH $\Rightarrow$ 3 ATP

Each $FADH_2$ $\Rightarrow$ 2 ATP

1E Section(s) 20.8 Uses of Energy in Cells

- Molecular Synthesis
  - Anabolic Pathways

- To Generate Gradients via Active Pumps
  - H^+, K^+, etc.

- Mechanical Energy
  - Muscles
  - Molecular motors

- Heat

Problems: 20.1 to 20.49

Index of Topics and Vocabulary