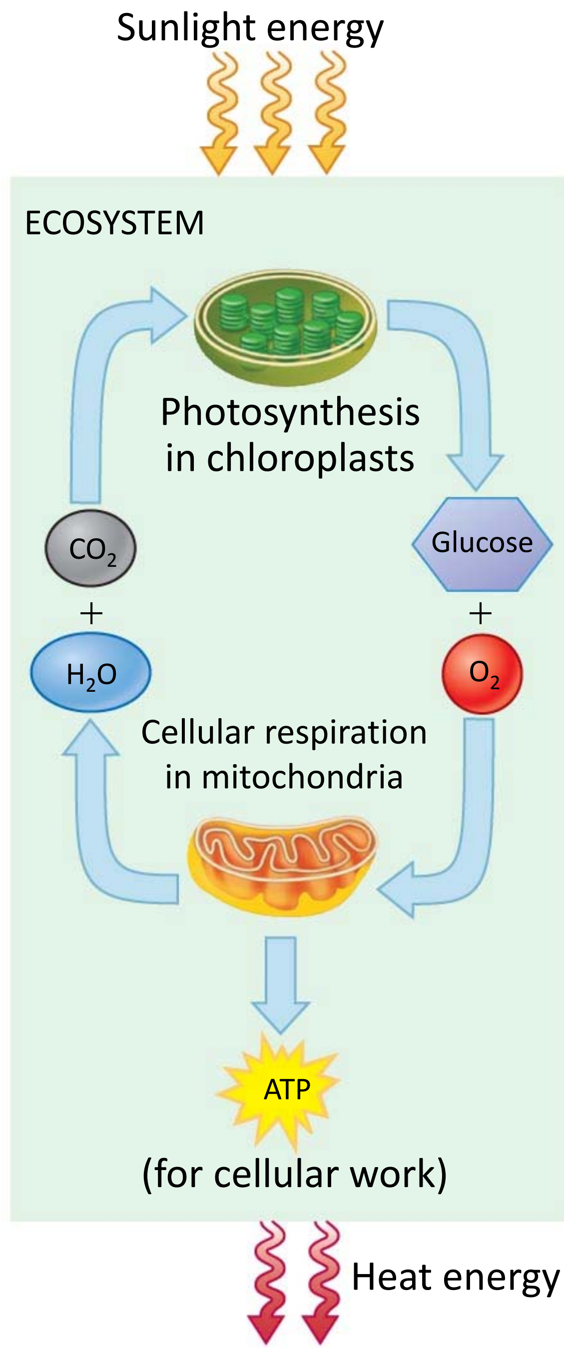
Chapter 6

How Cells Harvest Chemical Energy

Lecture by Dr. Fernando Prince

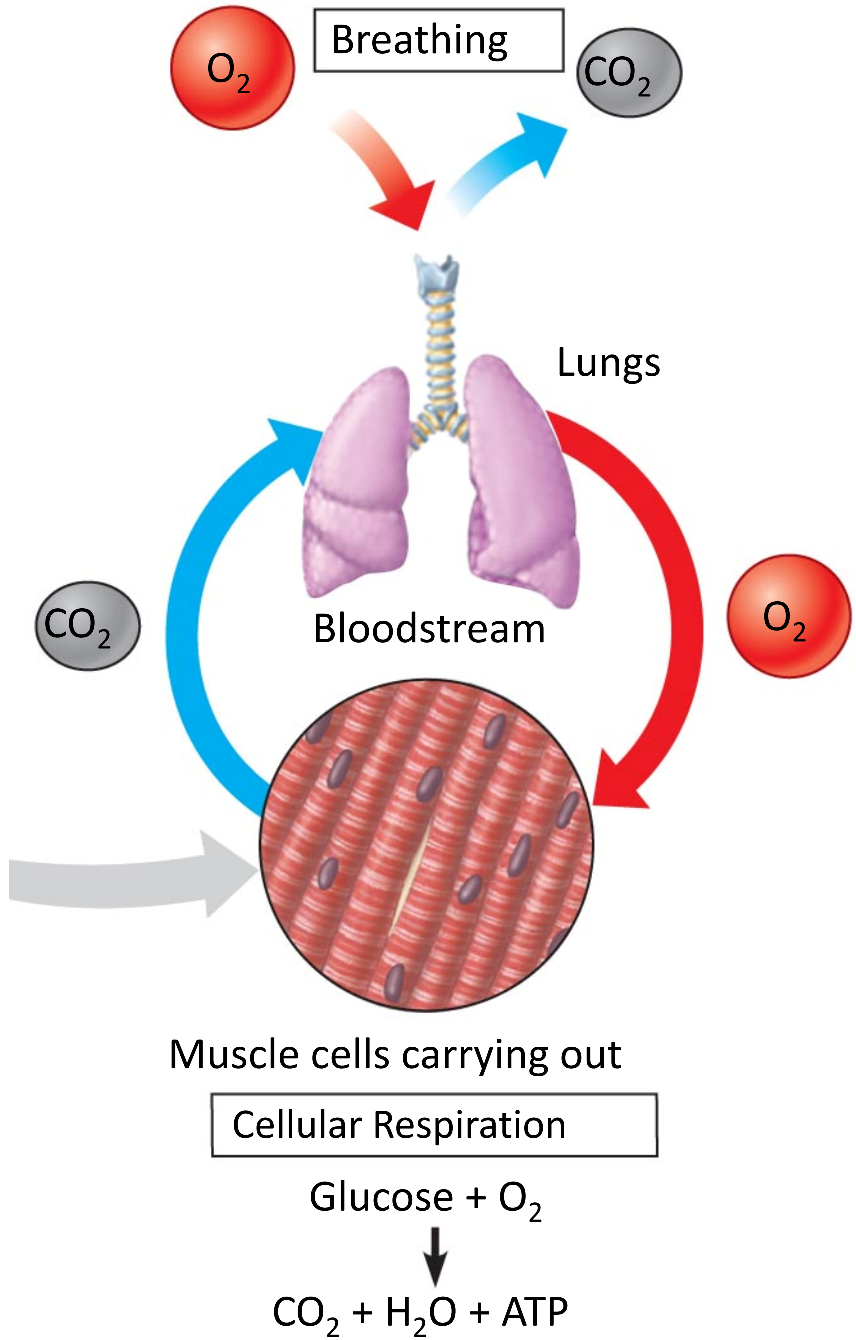
Energy in sunlight is used in photosynthesis to make glucose from CO_2 and H_2O with release of O_2



Other organisms use the O_2 and energy in sugar and release CO_2 and H_2O

Breathing is necessary for exchange of CO_2 produced during cellular respiration for atmospheric O_2

Cellular respiration uses O_2 to help harvest energy from glucose and produces CO_2 in the process



Stages of Metabolism

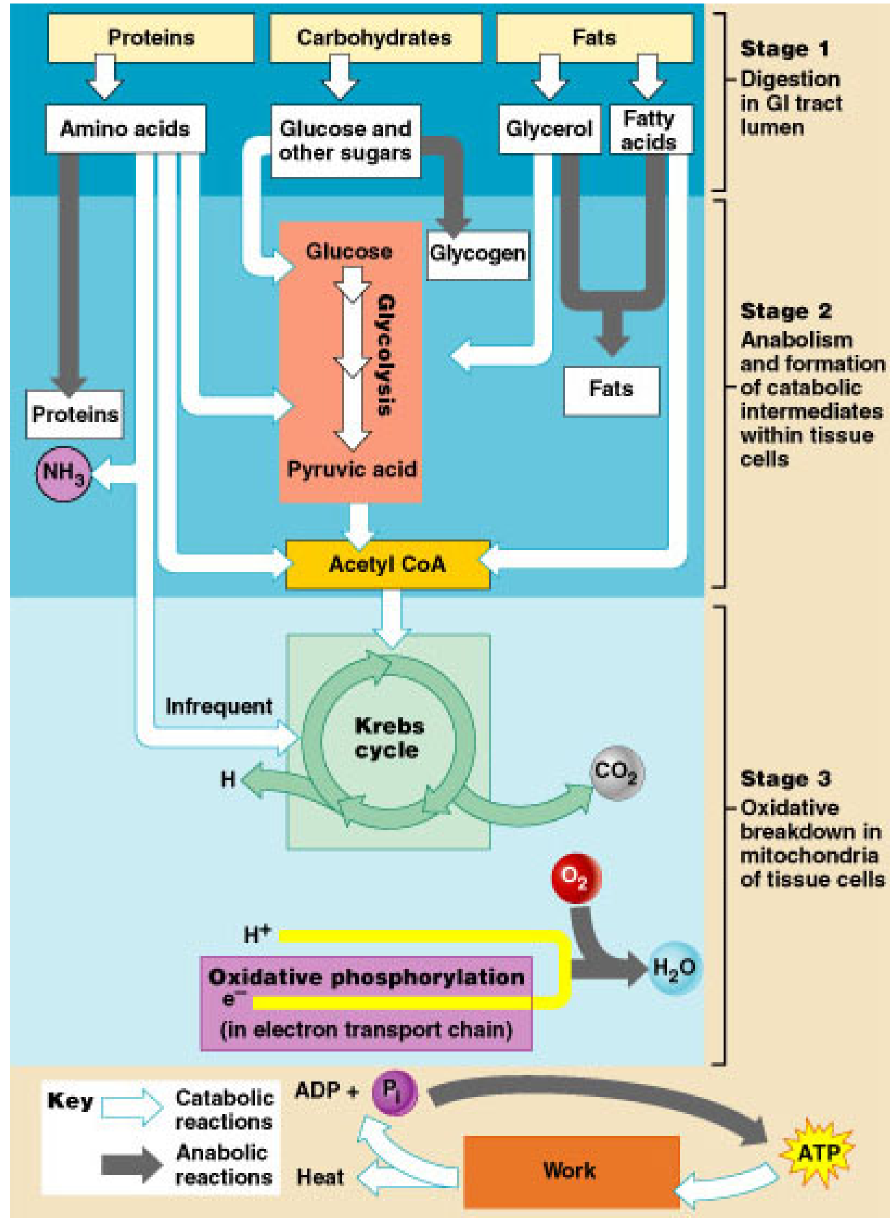


Figure 24.3

Oxidation-Reduction (Redox) Reactions

- Whenever one substance is oxidized, another substance is reduced
- Oxidized substances lose energy (loss of electron)
- Reduced substances gain energy (gain of electron)
- Two important coenzymes are nicotinamide adenine dinucleotide (NAD^+) and flavin adenine dinucleotide (FAD) act as hydrogen acceptors

Mechanisms of ATP Synthesis: Substrate-Level Phosphorylation

- High-energy phosphate groups are transferred directly from phosphorylated substrates to ADP
- ATP is synthesized via substrate-level phosphorylation in glycolysis and the Krebs cycle

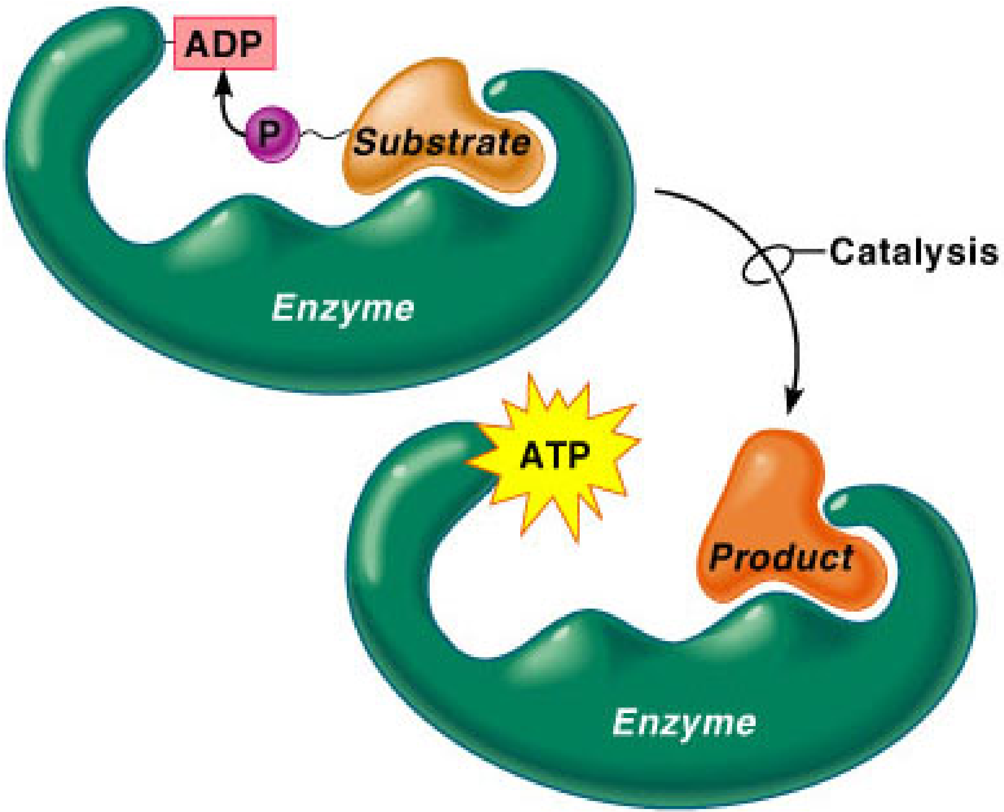


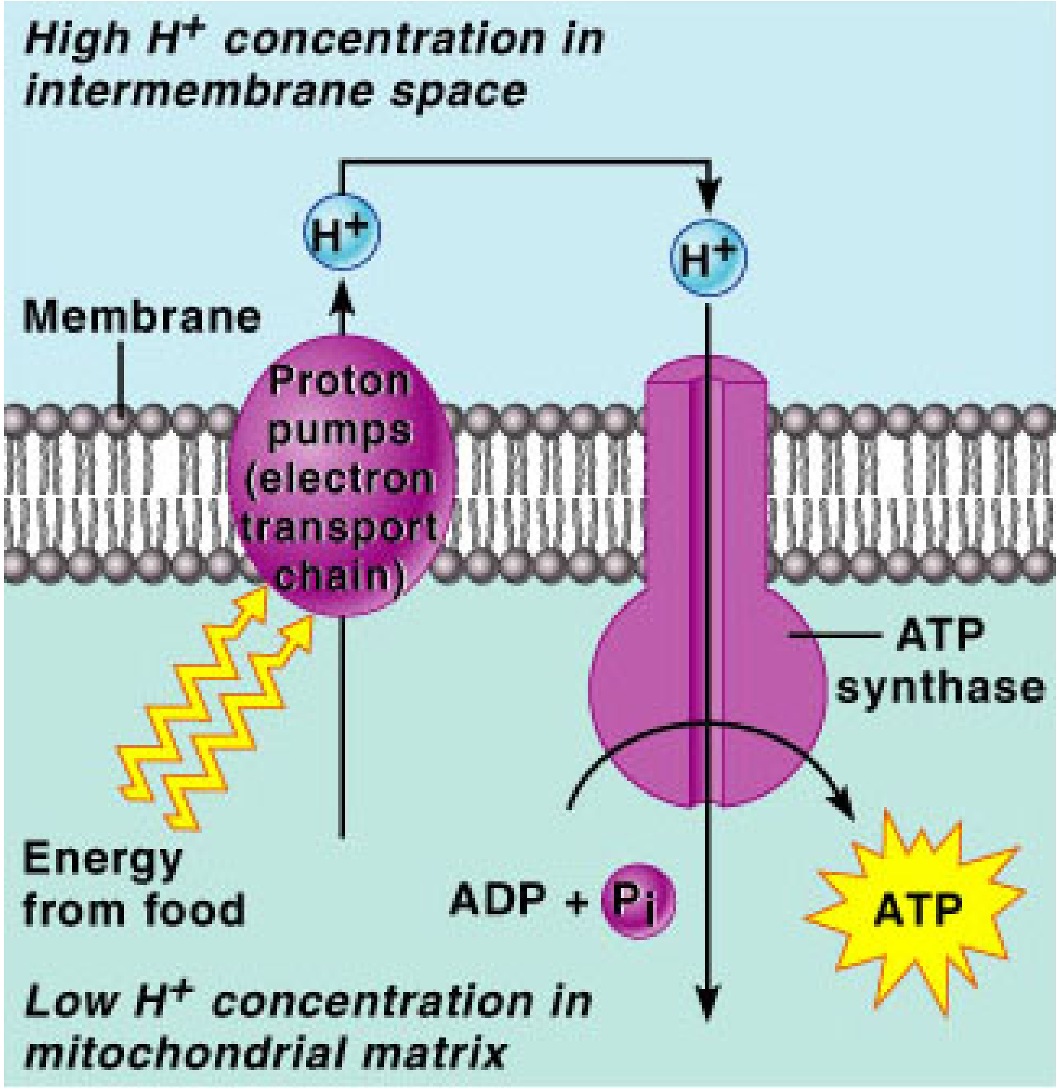
Figure 24.4a

Mechanisms of ATP Synthesis: Oxidative Phosphorylation

- Is carried out by the electron transport proteins in the cristae of the mitochondria
  - Nutrient energy is used to pump hydrogen ions into the intermembrane space
  - A steep diffusion gradient across the membrane results
  - When hydrogen ions flow back across the membrane through ATP synthase, energy is captured and attaches phosphate groups to ADP (to make ATP)

Mechanisms of ATP Synthesis: Oxidative Phosphorylation

Chemiosmotic process use the energy in the movement of substances across a membrane, coupled to chemical reactions to generate ATP



Carbohydrate Metabolism

- Since all carbohydrates are transformed into glucose, it is essentially glucose metabolism
- Oxidation of glucose is shown by the overall reaction:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2 + 36\ ATP + heat$$

- Glucose is catabolized in three pathways
  - Glycolysis
  - Krebs cycle
  - The electron transport chain and oxidative phosphorylation

Carbohydrate Catabolism

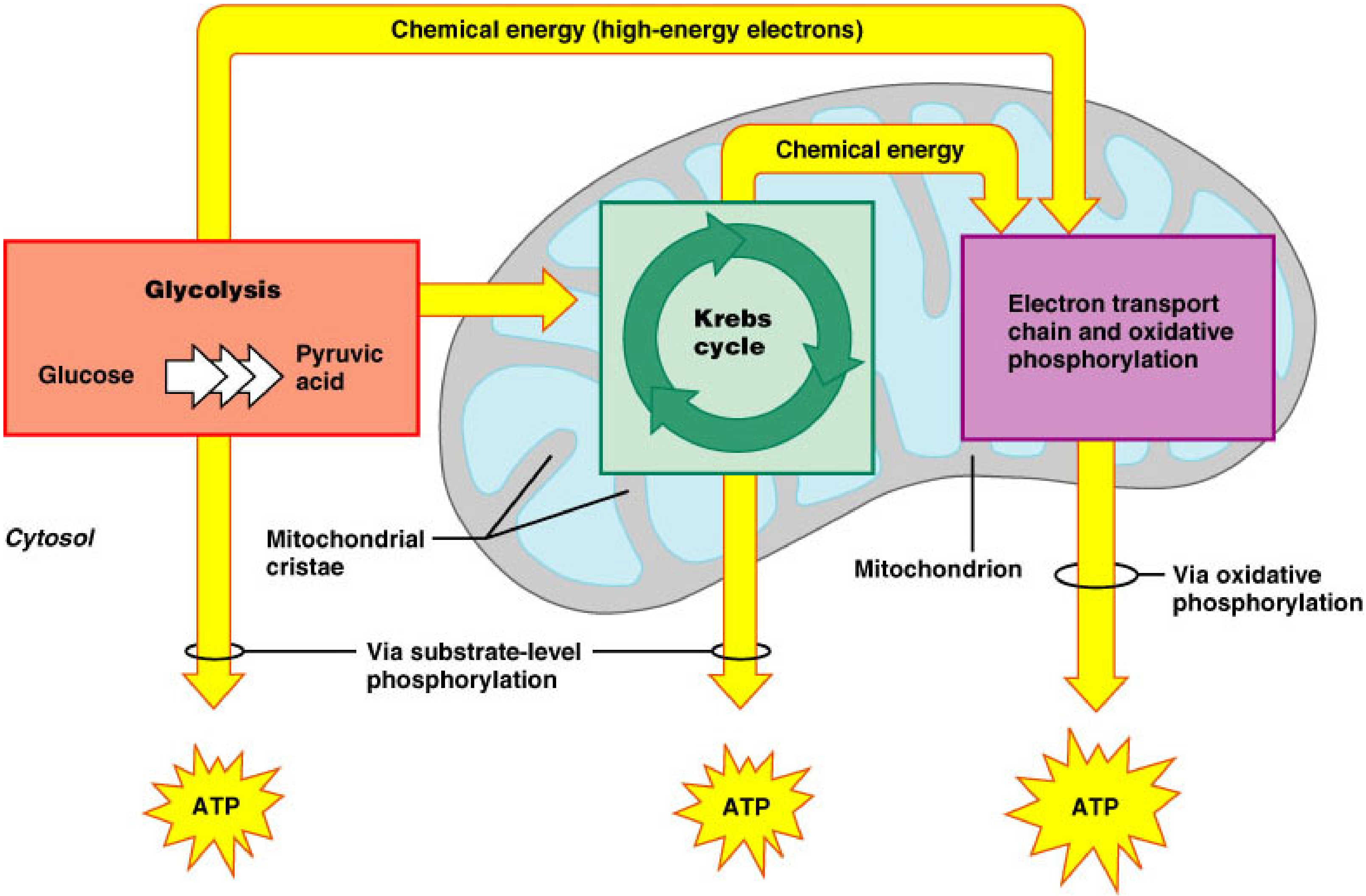
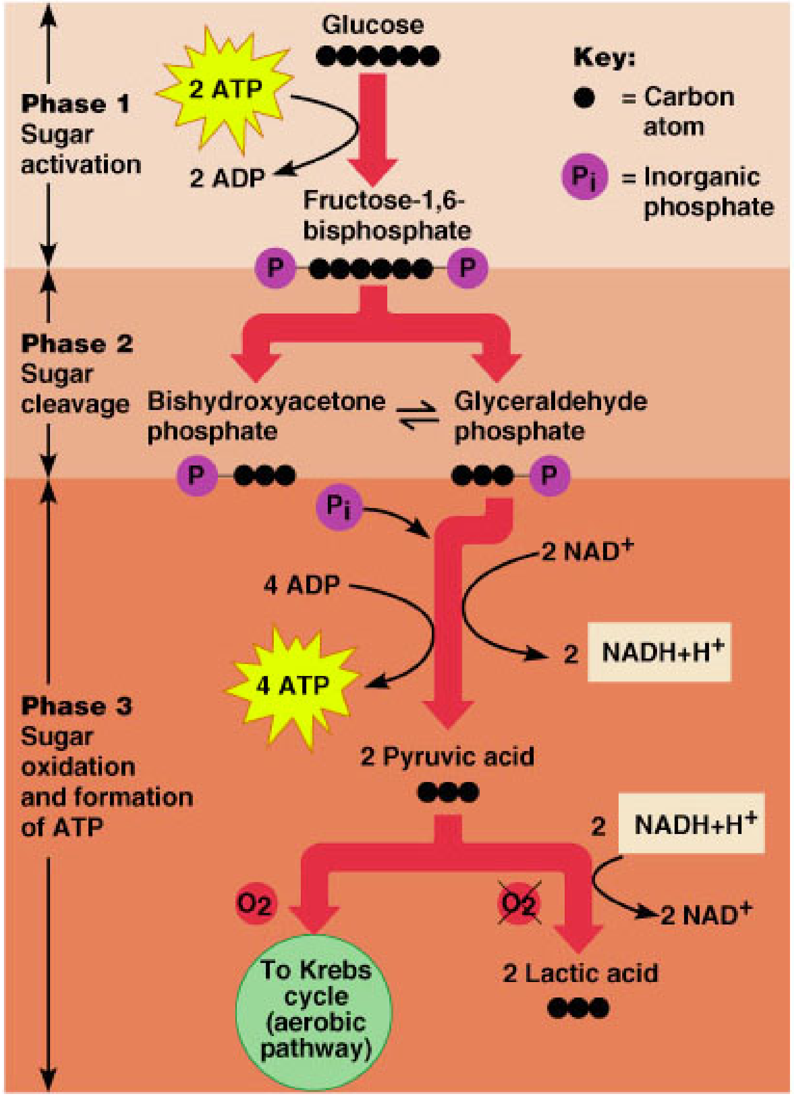


Figure 24.5

Glycolysis

- A three-phase pathway in which:
  - Glucose is oxidized into pyruvic acid
  - NAD^+ is reduced to $NADH + H^+$
  - ATP is synthesized by substrate-level phosphorylation
- Pyruvic acid:
  - Moves on to the Krebs cycle in an aerobic pathway
  - Is reduced to lactic acid in an anaerobic environment

Glycolysis



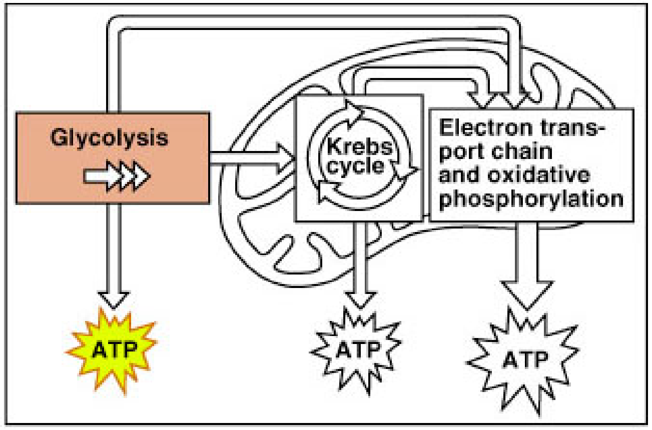


Figure 24.6

Glycolysis: Phase 1 and 2

- Phase 1: Sugar activation
  - Two ATP molecules activate glucose into fructose-1,6-diphosphate
- Phase 2: Sugar cleavage
  - Fructose-1,6-bisphosphate is cleaved into two 3-carbon isomers
    - Bishydroxyacetone phosphate
    - Glyceraldehyde 3-phosphate

Glycolysis: Phase 3

- Phase 3: Oxidation and ATP formation
  - The 3-carbon sugars are oxidized (reducing NAD^+)
  - Inorganic phosphate groups (P_i) are attached to each oxidized fragment
  - The terminal phosphates are cleaved and captured by ADP to form four ATP molecules

The final products are:

Two pyruvic acid molecules

Two $NADH + H^+$ molecules (reduced NAD^+)

A net gain of two ATP molecules

Krebs Cycle: Preparatory Step

- Occurs in the mitochondrial matrix and is fueled by pyruvic acid and fatty acids
- Pyruvic acid is converted to acetyl CoA in three main steps:
  - Decarboxylation
    - Carbon is removed from pyruvic acid
    - Carbon dioxide is released

Krebs Cycle: Preparatory Step

- Oxidation
  - Hydrogen atoms are removed from pyruvic acid
  - NAD^+ is reduced to $NADH + H^+$
- Formation of acetyl CoA – the resulting acetic acid is combined with coenzyme A, a sulfur-containing coenzyme, to form acetyl CoA

Krebs Cycle

- An eight-step cycle in which each acetic acid is decarboxylated and oxidized, generating:
  - Three molecules of NADH + H^+
  - One molecule of $FADH_2$
  - Two molecules of CO_2
  - One molecule of ATP
- For each molecule of glucose entering glycolysis, two molecules of acetyl CoA enter the Krebs cycle

Krebs Cycle

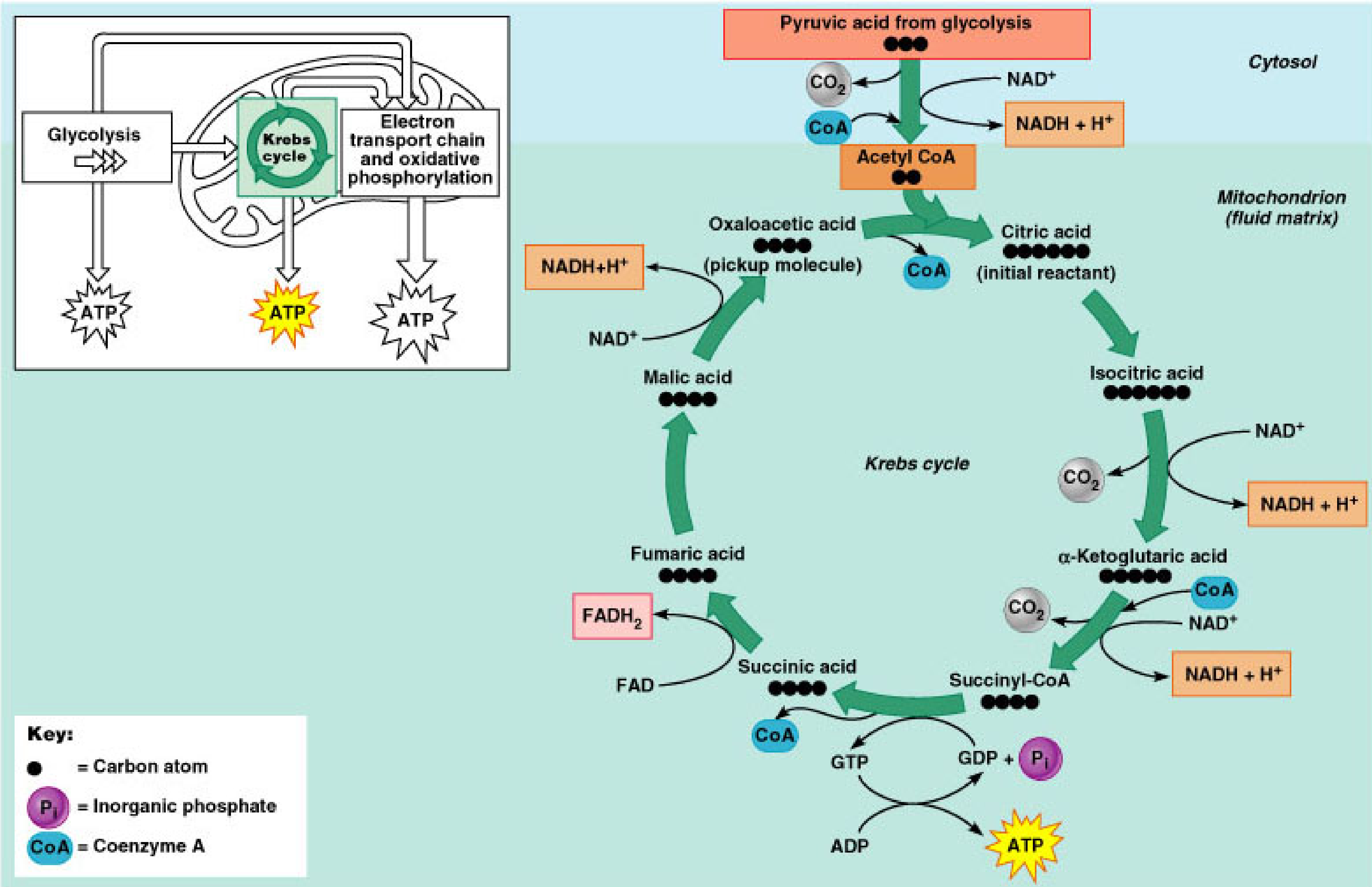


Figure 24.7

Electron Transport Chain

- Food (glucose) is oxidized and the released hydrogens:
  - Are transported by coenzymes NADH and $FADH_2$
  - Enter a chain of proteins bound to metal atoms (cofactors)
  - Combine with molecular oxygen to form water
  - Release energy
- The energy released is harnessed to attach inorganic phosphate groups (P_i) to ADP, making ATP by oxidative phosphorylation

Mechanism of Oxidative Phosphorylation

- The hydrogens delivered to the chain are split into protons (H^+) and electrons
  - The protons are pumped across the inner mitochondrial membrane by:
    - NADH dehydrogenase (FMN, Fe-S)
    - Cytochrome b-c_1
    - Cytochrome oxidase (a-a_3)
  - The electrons are shuttled from one acceptor to the next

Mechanism of Oxidative Phosphorylation

- Electrons are delivered to oxygen, forming oxygen ions
- Oxygen ions attract H^+ to form water
- H^+ pumped to the intermembrane space:
  - Diffuses back to the matrix via ATP synthase
  - Releases energy to make ATP

Mechanism of Oxidative

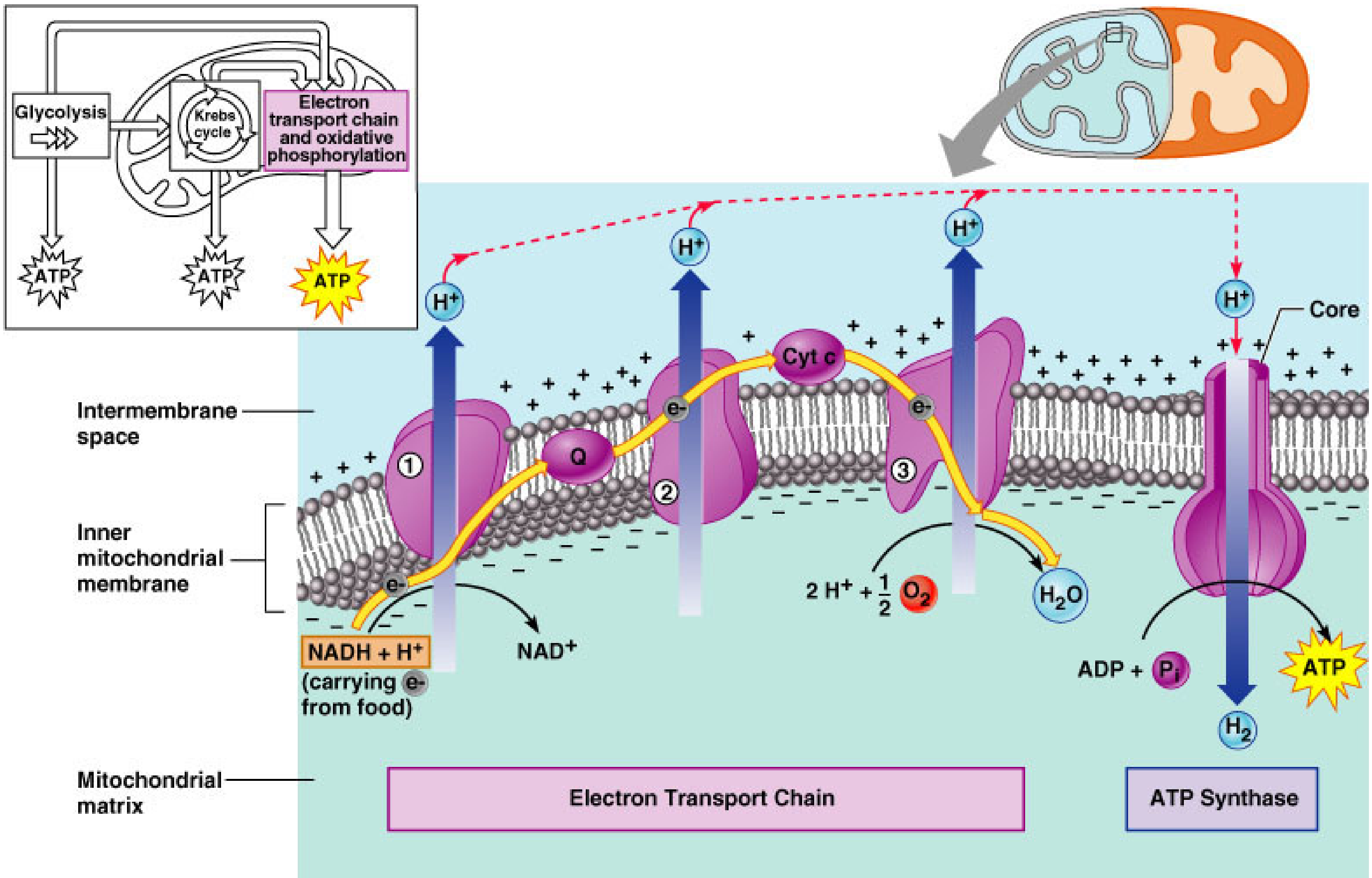


Figure 24.8

Electronic Energy Gradient

- The transfer of energy from NADH + H^+ and $FADH_2$ to oxygen releases large amounts of energy
- This energy is released in a stepwise manner through the electron transport chain

Electronic Energy Gradient

- The electrochemical proton gradient across the inner membrane:
  - Creates a pH gradient
  - Generates a voltage gradient
- These gradients cause H^+ to flow back into the matrix via ATP synthase

Electronic Energy Gradient

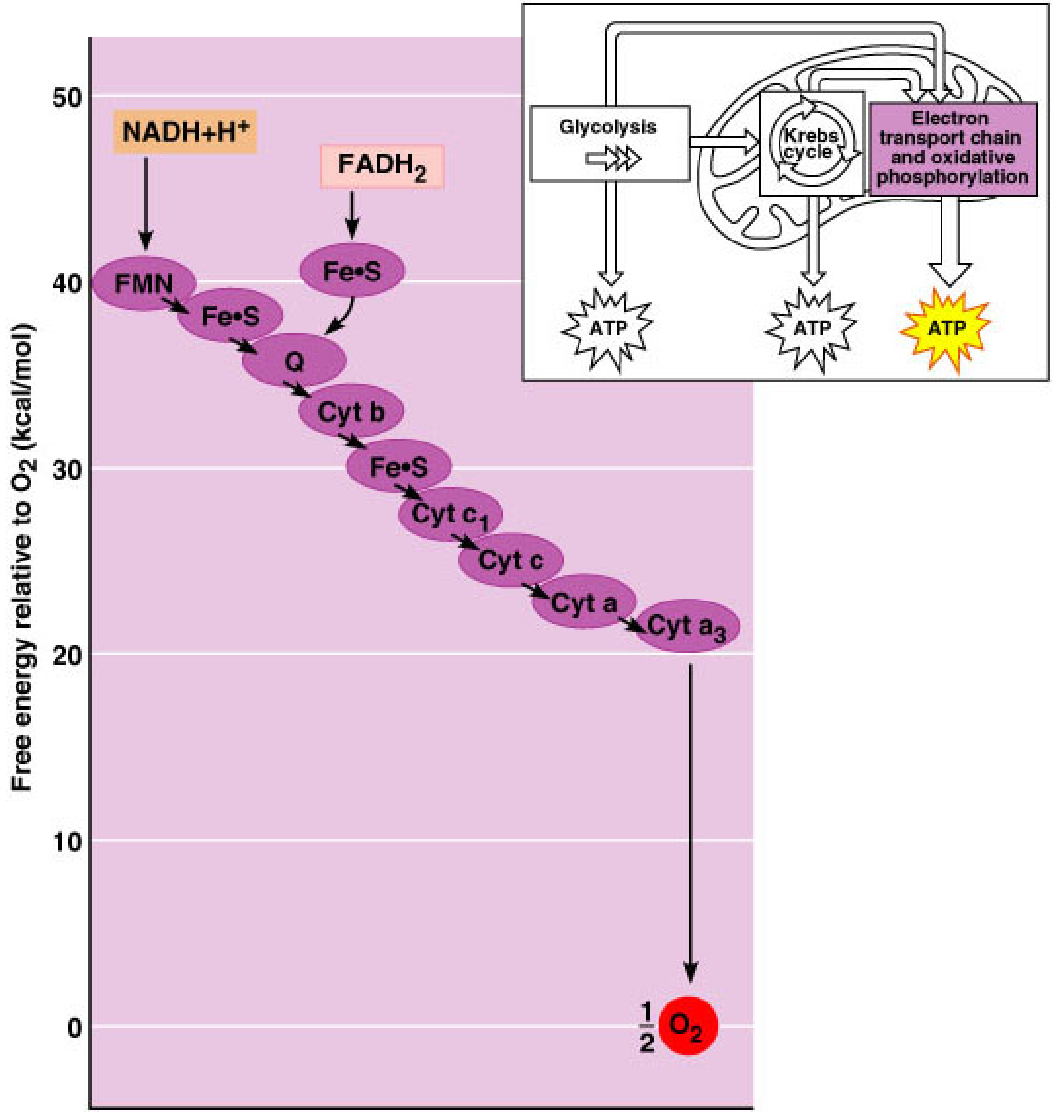
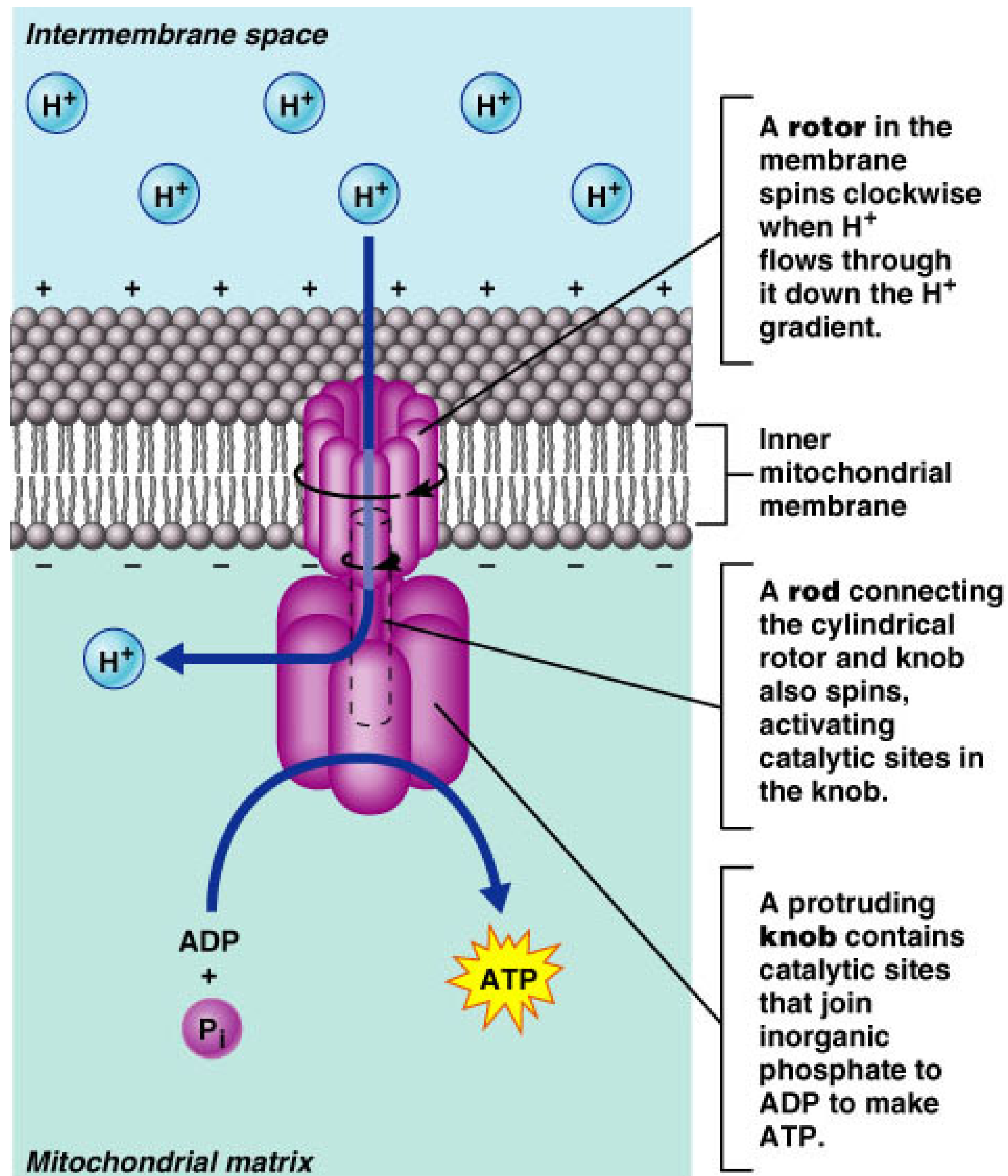


Figure 24.9

Structure of ATP Synthase



Summary of ATP Production

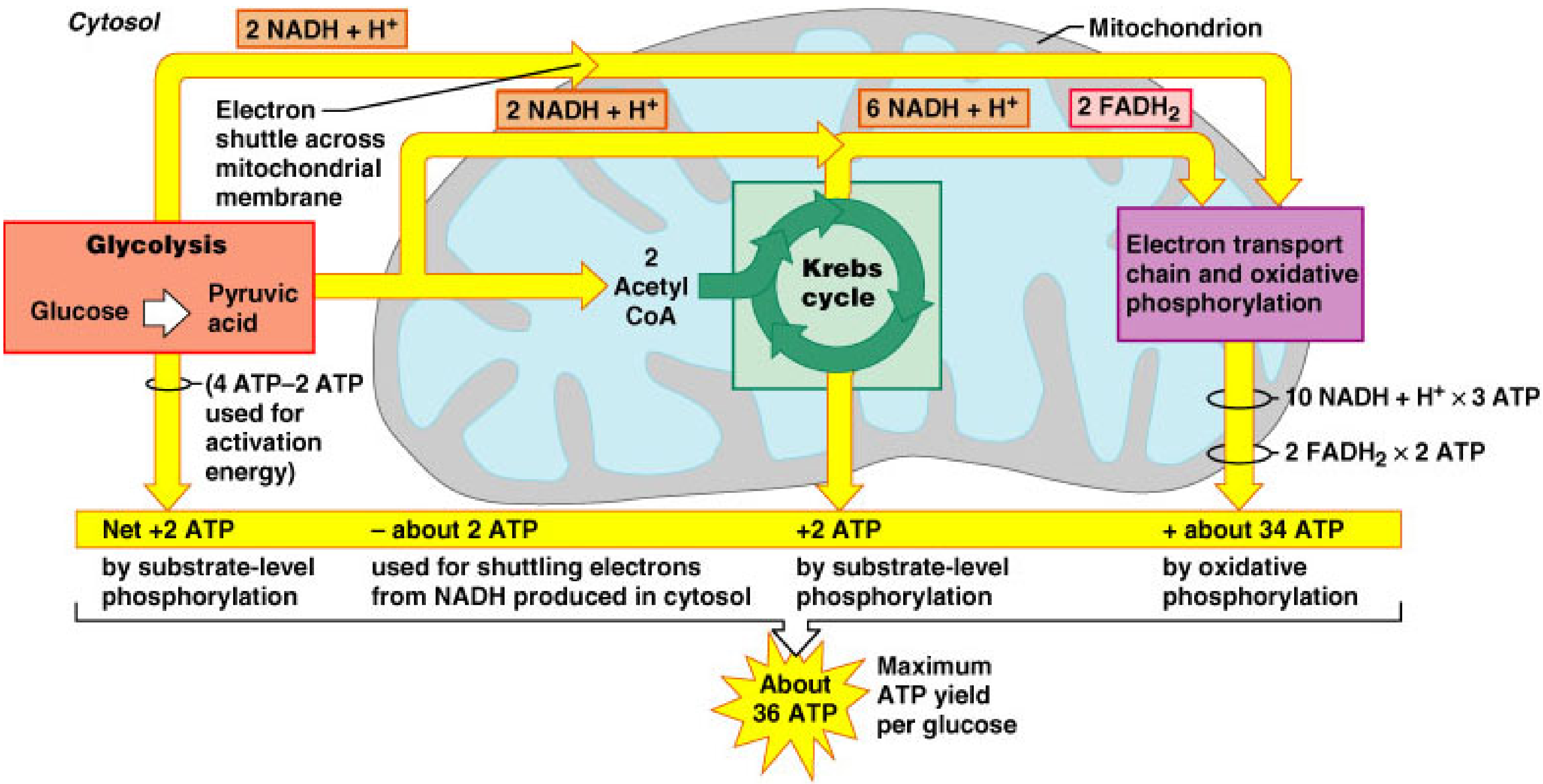


Figure 24.11