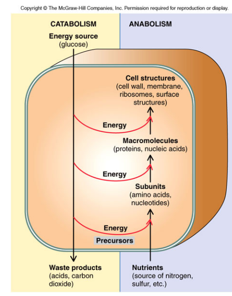
Chapter 6

Metabolism

Principles of Metabolism

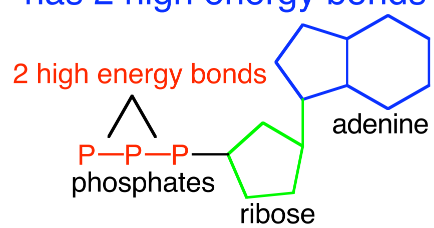
- ✓ Catabolism
  - Degradative reactions
  - Reactions produce energy from the break down of larger molecules
- ✓ Anabolism
  - Reactions involved in the synthesis of cell components
  - Anabolic reactions require energy
    - Anabolic reactions utilize the energy produced from catabolic reactions



Types of energy

- ✓ Potential energy
  - Stored energy
- ✓ Kinetic energy
  - Energy of movement

ATP has 2 high energy bonds



- ATP is created 3 ways
  - Substrate phosphorylation - uses chemical energy
  - Oxidative phosphorylation - uses chemical energy to form a proton motive force
  - Photophosphorylation - uses light energy to form a proton motive force

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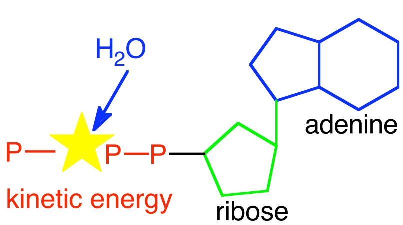
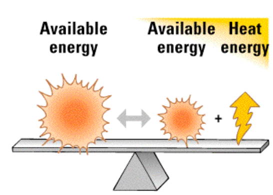
Breaking bonds releases energy

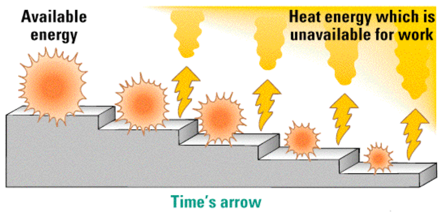


First Law of Thermodynamics



Conservation of energy:
energy is neither gained nor lost, it is only transformed.

Second Law of Thermodynamics

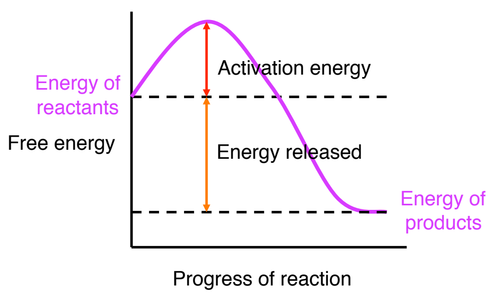


Energy available for work decreases as energy is lost to heat.

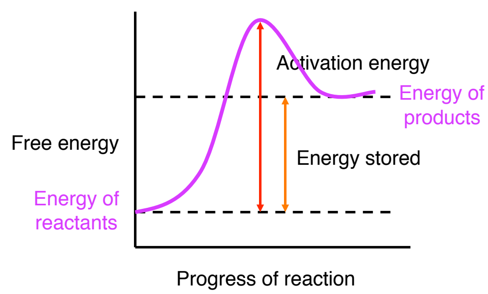
Reactions

- ✓ Exergonic
  - ✑Energy-releasing reactions.
- ✓ Endergonic
  - ✑Energy-storing reactions.
- ✓ Coupled reactions
  - ✑Exergonic reactions often provide the energy for endergonic reactions.
  - ✑Enzymes mediate the coupling.

Exergonic reactions



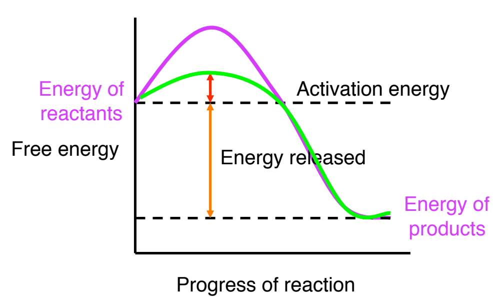
Endergonic reactions



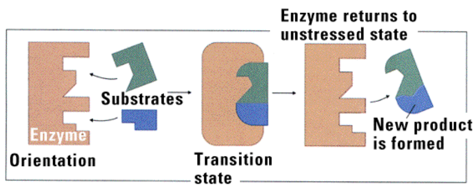
Enzymes...

- ✓ Are biochemical catalysts.
- ✓ Speed up reactions.
- ✓ Are not used up by the reaction they catalyze.
- ✓ Lower the activation energy of the reaction.
- ✓ Are usually proteins.
- ✓ Are usually influenced by pH, temperature, and the concentration of the substrate.
- ✓ Influenced by inhibitors

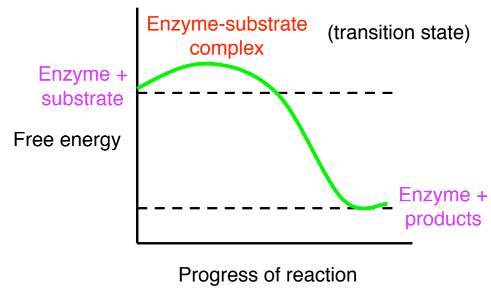
Enzymes lower the activation energy



Biological reactants are called substrates



Enzymes form a complex with the substrate



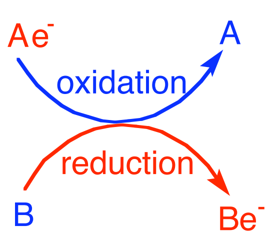
Enzymes can be inhibited

- ✓ Competitive inhibitors.
  - ✑Compete with the substrate for the active site of the enzyme.
  - ✑Often are steric in nature.
- ✓ Noncompetitive inhibitors.
  - ✑Bind to another site on the enzyme and deactivate the active site.
    - ⇾(allosteric)
- ✓ Feedback inhibition

Oxidation-Reduction Reactions

- ✓ Loss of electrons is OXIDATION.
  - ✑Loss of energy
  - ✑Loss of hydrogen
- ✓ Gain of electrons is REDUCTION.
  - ✑Gain of energy
  - ✑Gain of hydrogen

Oxidation-reduction reactions are coupled

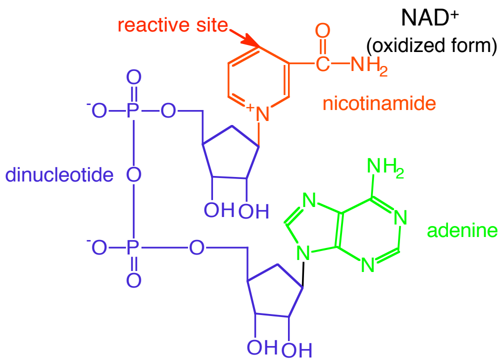


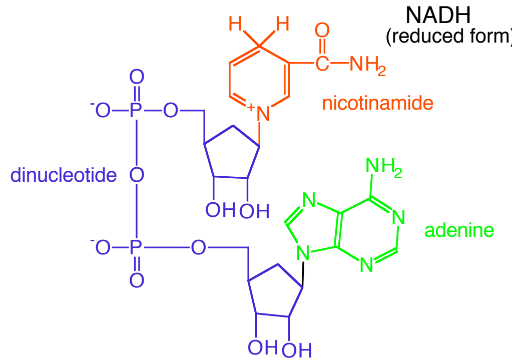
Common electron acceptors

- ✓ Nicotinamide adenine dinucleotide (NAD^+)
- ✓ Flavin adenine dinucleotide (FAD^+)
- ✓ Nicotinamide adenine dinucleotide phosphate ($NADP^+$)

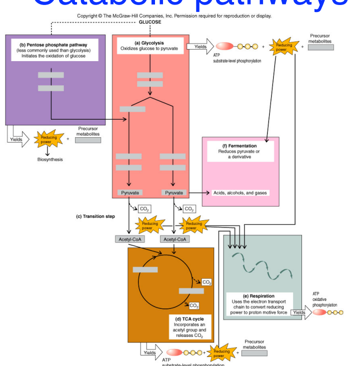
$$NAD^+ + 2e^- + 2H^+ \rightarrow NADH + H^+$$

oxidized form reduced form





Catabolic pathways



- ✓ Three key pathways
  - Central metabolic pathways
    - Glycolysis
    - Pentose phosphate pathway
    - Tricarboxcylic acid cycle or Krebs
- ✓ Central pathways are catabolic and provide
  - Energy
  - Reducing power
  - Precursor metabolites

Carbon source

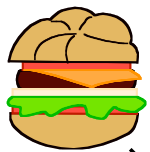
- ✓ Autotrophs
- ✓ Use inorganic C, mainly CO_2, as a C source.
- ✓ Heterotrophs
- ✓ Use organic C as a C source

Energy source

- ✓ Phototrophs
- ✓ Use light as an energy source.
- ✓ Chemotrophs
- ✓ Use organic or inorganic compounds as energy sources.

Carbon and Energy Sources

	carbon source	energy source
chemoautotrophs	CO_2	inorganic molecules
chemoheterotrophs	organic molecules	organic molecules
photoautotrophs	CO_2	light
photoheterotrophs	organic molecules	light



carbohydrates fats protein

metabolism

Catabolic Pathways

- ✓ Glycolysis
  - a.k.a Embden-Myerhoff pathway
  - Oxidizes glucose to two molecules of pyruvate
- ✓ Pentose phosphate pathway (PPP)
  - Breaks down glucose
  - Produces molecules for biosynthesis
  - Works in conjunction with glucose degrading pathways
- ✓ Tricarboxylic acid cycle (TCA) or Krebs
  - Before entering cycle, pyruvate enters transition step
    - Pyruvate formed in glycolysis and PPP
  - Cycle turns twice to complete oxidation of one glucose molecule
- ✓ Respiration vs. fermentation
  - Respiration uses reducing power to generate ATP
    - NADH and $FADH_2$ transfer electrons to produce proton motive force
      - Allows for recycling of electron carriers
    - Electrons join with terminal electron acceptor
      - Oxygen in aerobic respiration
      - Anaerobic respiration uses another inorganic molecule
  - Fermentation is partial oxidation of glucose
    - Produces very little ATP
    - Uses pyruvate or derivative as terminal electron acceptor
      - Other organisms may use other organic molecules as terminal electron acceptor

Cellular Respiration

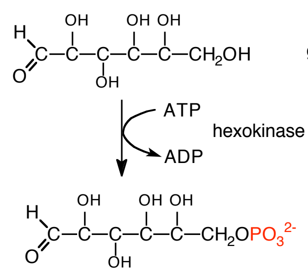
glycolysis

Anaerobic respiration → pre-Krebs cycle

Anaerobic respiration → fermentation

pre-Krebs cycle → Aerobic respiration Krebs cycle → electron transport system

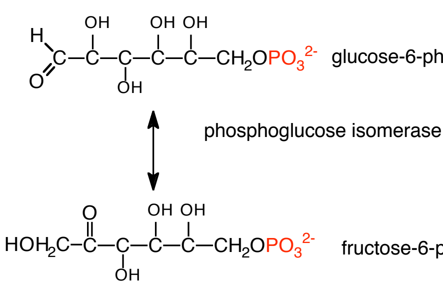
Phosphorylation prevents glucose from leaving the cell



glucose

glucose-6-phosphate

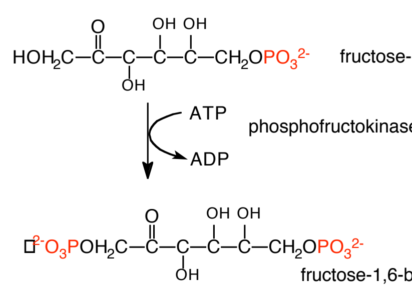
Aldose to ketose



glucose-6-phosphate

fructose-6-phosphate

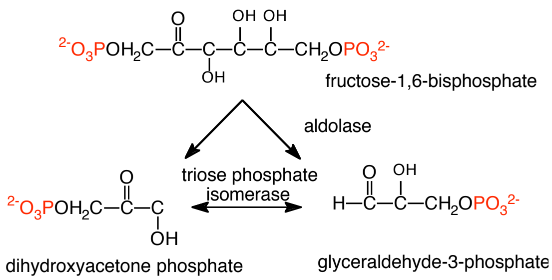
Phosphofructokinase is the key enzyme in glycolysis



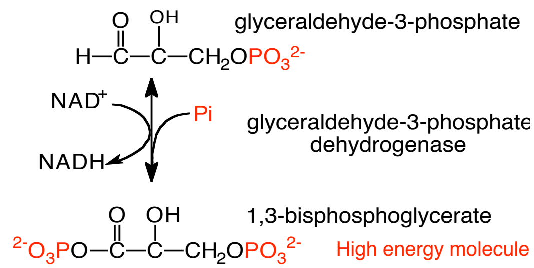
fructose-6-phosphate

fructose-1,6-bisphosphate

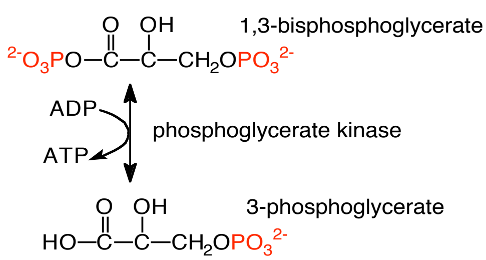
Sugar-splitting



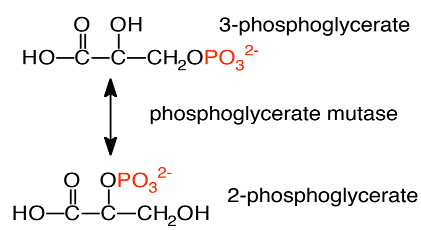
Energy transfer



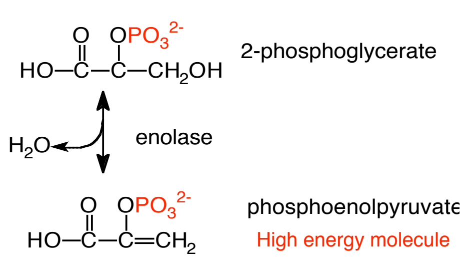
Forming ATP



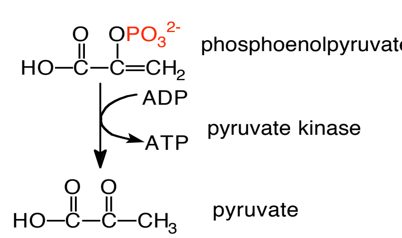
Rearrangement



Dehydration increases the potential for transfer of phosphate to ADP



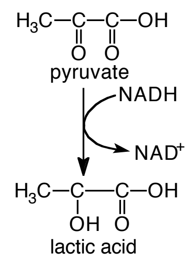
Transfer of P to ADP is irreversible



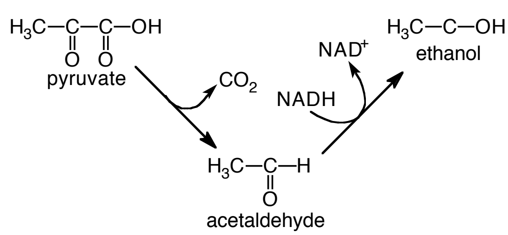
Fermentation

- ✓ Anaerobic process
  - ✑Formation of 2 ATP (net) in glycolysis.
  - ✑Regeneration of NAD^+

Lactic acid fermentation



Alcoholic fermentation



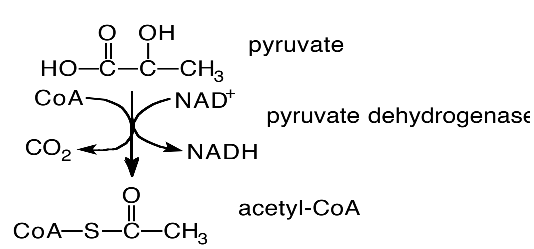
Other fermentations

- ✓ Mixed acid fermentation
  - ✑Acetic acid, succinic acid, ethanol, CO_2, H_2.
- ✓ Propionic fermentation
  - ✑Propionic acid, acetic acid, CO_2
- ✓ Butanediol fermentation
  - ✑Butanediol,
- ✓ Butyric-butylic fermentation
  - ✑Butanol, isopropanol, acetone, CO_2

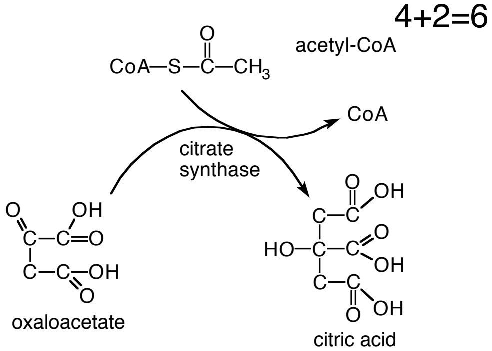
Krebs cycle

- ✓ A sequence of reactions by which acetyl (2C) groups are oxidized to CO_2.
- ✓ Hydrogen groups are removed and electrons are transferred to NAD^+ and FAD^+.

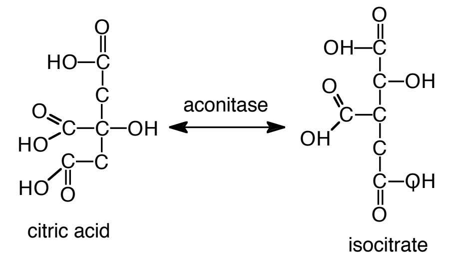
CoA activates the carbons from pyruvate



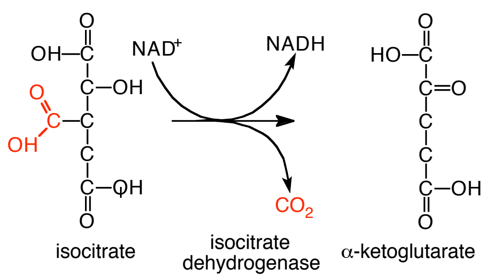
4+2=6



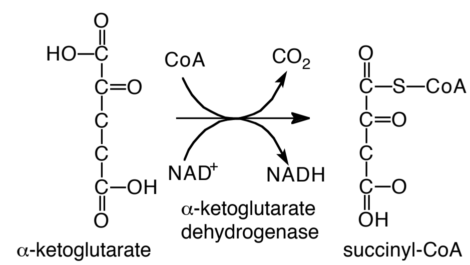
Moving an -OH



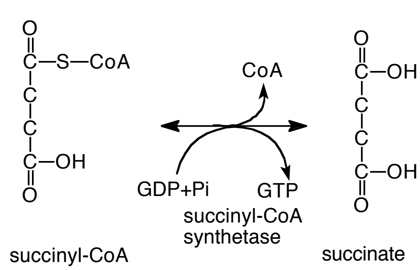
Oxidation and decarboxylation



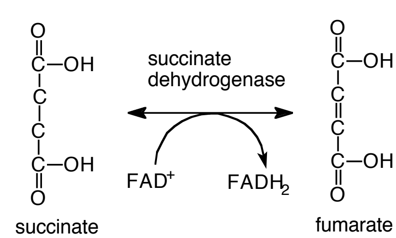
Energizing the bonds



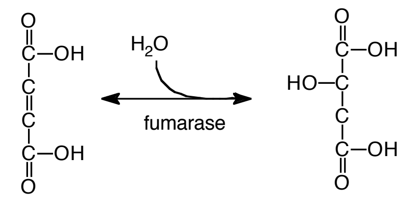
Making ATP



Using FAD^+

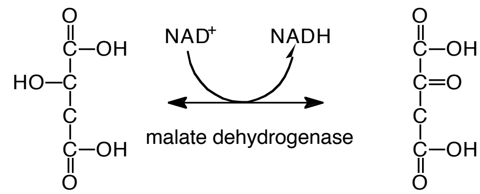


Hydrating fumarate



fumarate → malate

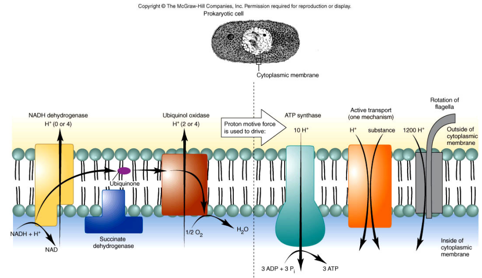
Oxidation of malate



malate → oxaloacetate

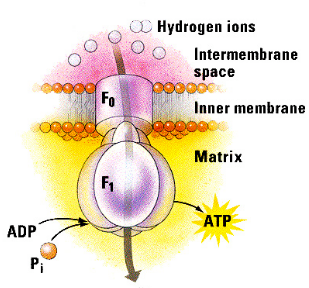
Krebs cycle summary

IN	OUT
✑2 acetyl-CoA	✑$2CO_2$
✑6 NAD^+	✑6NADH
✑2 FAD^+	✑$2FADH_2$
✑2GDP	✑2GTP
✑2Pi	✑$2H^+$
✑$2H_2O$	✑2 CoA



- Electron transport chain
  - Group of membrane-embedded electron carriers
    - Arrangement of carriers aids in production of proton motive force
  - Four types of electron carriers
    - Flavoproteins
    - Iron-sulfur proteins
    - Quinones
    - Cytochromes

ATP synthase uses energy from a proton motive force



Krebs cycle leads to 20 ATP

IN	OUT
✑2 acetyl-CoA	✑$4CO_2$
✑6 NAD^+	✑6NADH = 15ATP
✑2 FAD^+	✑$2FADH_2$ = 3ATP
✑2GDP	✑2GTP = 2ATP
✑2Pi	✑$2H^+$
✑$2H_2O$	✑2 CoA

Energy summary

- ✓ Glycolysis
  - ✑4ATP
  - ✑2NADH
- ✓ Pre-Kreb's cycle
  - ✑2NADH
- ✓ Kreb's cycle
  - ✑6NADH
  - ✑2$FADH_2$
  - ✑2GTP

- ✓ Glycolysis
  - ✑7 ATP
- ✓ Pre-Kreb's cycle
  - ✑5 ATP
- ✓ Kreb's cycle
  - ✑20 ATP

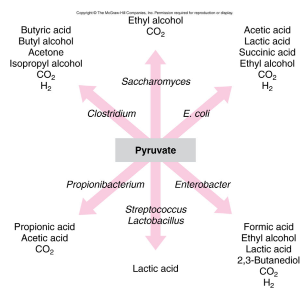
Total = 32 ATP

Anaerobic Respiration

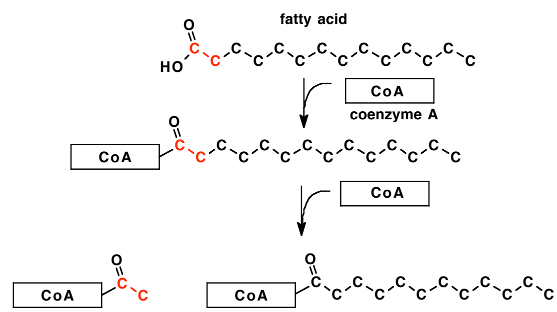
- ✓ Alternate terminal electron acceptors are used in the ETS.
  - ✑Nitrate, sulfate, iron
- ✓ Not as much energy is produced as when oxygen is used (aerobic respiration).

Fermentation

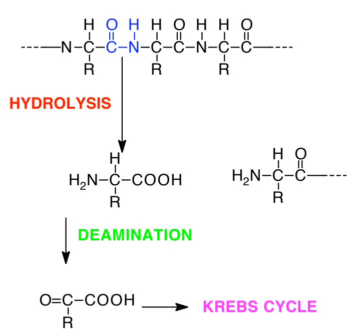
- ✓ Reduction of pyruvate.
- ✓ Anaerobic process.
- ✓ Regenerates NAD^+
- ✓ Produces very little energy (2ATPs)
- ✓ Produces lactic acid, ethyl alcohol, CO_2, H_2, acetic acid, succinic acid, propionic acid, butyric acid etc.



Fat metabolism



Protein metabolism



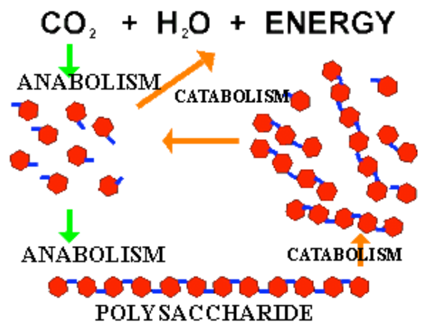
Respiration (review)

Producing energy for the cell

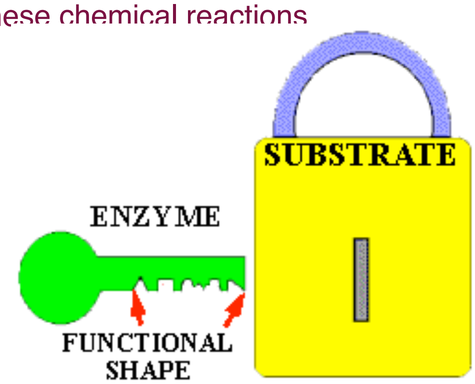
Respiration (background)

- ✓ Metabolism
  - Sum of all chemical reactions in the cell
    - **Catabolism** is the conversion of complex molecules to simpler and smaller molecules. This usually involves the release of useful energy for the cell. Example: Glucose + oxygen --> carbon dioxide, water, and energy.
    - **Anabolism** is the conversion of simple molecules to larger and more complex molecules. This usually involves the input of energy into the system to create the new covalent bonds needed to form the more complex molecules created. Example: glucose + glucose + glucose + glucose + ENERGY --> glycogen (starch)

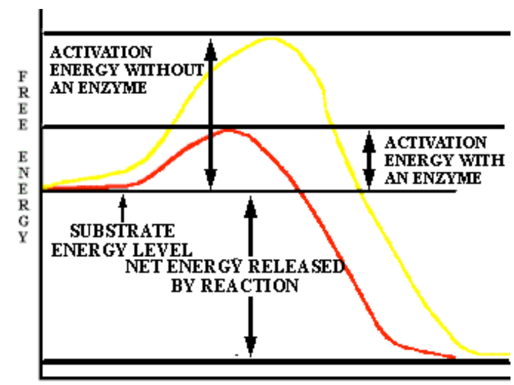
Catabolism and Anabolism



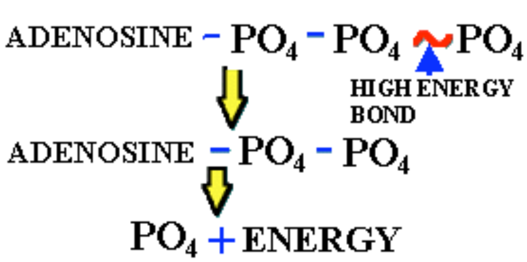
Enzymes are used by the cell to control these chemical reactions



Enzymes lower the energy of activation



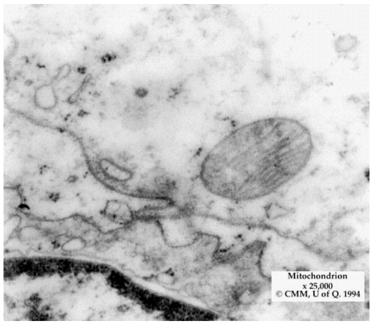
ATP (energy source of the cell) (GTP?)



Overview of respiration

- ✓ nicotinamide adenine dinucleotide (NAD^+)
- ✓ flavin adenine dinucleotide (FAD)
- ✓ NADH and $FADH_2$ are coenzymes that are used to shuttle electrons to there final receptor in many cells.
- ✓ NADH and $FADH_2$ are coupled to the production of ATP by the process of oxidative phosphorylation.
- ✓ The pathway through a series of electron carriers is the electron transport chain (respiratory chain)
- ✓ The electron transport chain creates a proton gradient that produces ATP using an ATP synthase (chemiosmosis)

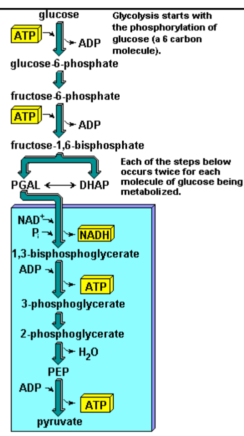
The mitochondria is the site for oxidative phosphorylation in eukaryotes- the cell membrane is the site in prokaryotes



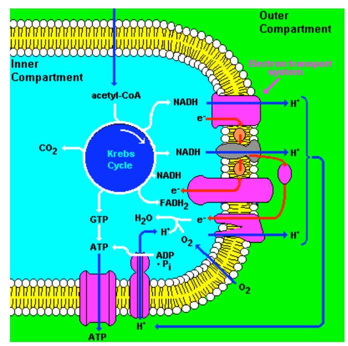
Types of respiration

- ✓ Aerobic respiration
  - O_2 is the electron acceptor
- ✓ Anaerobic respiration
  - An acceptor other than O_2 is used
  - eg. NO_3^-, NO_2, SO_4^{2-} and elemental S and several metal ions such as Fe^{3+}, and fumarate
- ✓ Lithotrophic respiration
  - Inorganic molecules are used to produce energy
  - eg. H_2S
  - Oxidation of H_2S takes place in the periplasm
  - NADH is not used to shuttle the electrons

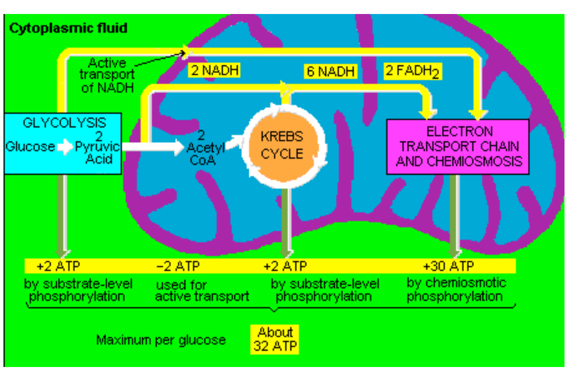
Glycolysis



Electron transport chain



Total energy obtained from one glucose molecule



Photosynthesis

- ✓ Light-capturing pigments
- ✓ Photosystems
- ✓ Photophosphorylation

Light-capturing pigments

✓ Chlorophylls
✓ Bacteriochlorophylls
✓ Carotenoids
✓ Phycobilins

Photosystems

✓ Reaction center pigments
✓ Accessory pigments (antennae pigments)

Photosystem

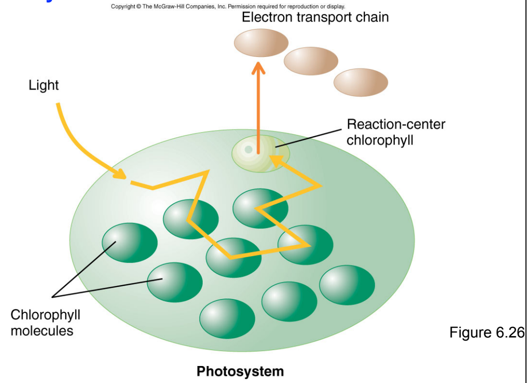


Figure 6.26

Photophosphorylation

✓ Tandem photosystems – cyanobacteria and plants
✓ Single photosystem – purple and green bacteria

Photosystem I and II

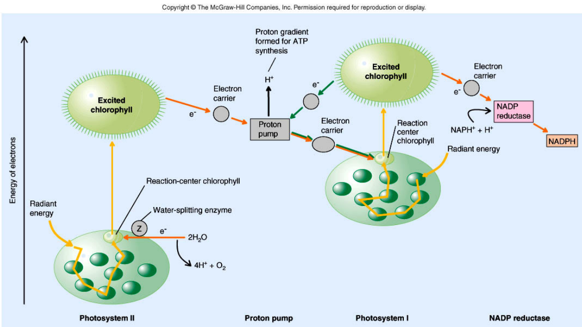


Figure 6.27

Photosynthetic mechanisms

Table 6.9 Comparison of the Photosynthetic Mechanisms Used by Different Organisms

	Oxygenic Photosynthesis		Anoxygenic Photosynthesis	
	Plants, Algae	**Cyanobacteria**	**Purple Photosynthetic Bacteria**	**Green Photosynthetic Bacteria**
Location of the photosystem	In membranes of thylakoids, which are within the stroma of chloroplasts.	In membranes of thylakoids, located within the cell.	Within the cytoplasmic membrane; extensive invaginations in that membrane effectively increase the surface area.	Primarily within the cytoplasmic membrane; chlorosomes attached to the inner surface of the membrane contain the accessory pigments.
Type of photosystem	Photosystem I and photosystem II		Similar to photosystem II	Similar to photosystem I
Primary light harvesting pigment	Chlorophyll *a*		Bacteriochlorophylls	
Mechanism for generating reducing power	Non-cyclic photophosphorylation using both photosystems		Reversed electron transport	Non-cyclic use of the photosystem
Source of electrons for reducing power	H_2O		Varies among the organisms in the group; may include H_2S, H_2, or organic compounds.	
CO_2 fixation	Calvin-Benson cycle		Calvin-Benson cycle	Reversed TCA cycle
Accessory pigments	Carotenoids	Carotenoids, phycobilins	Carotenoids	Carotenoids

Table 6.9

Carbon fixation

✓ Calvin cycle
✓ Reversed TCA cycle

Calvin Cycle

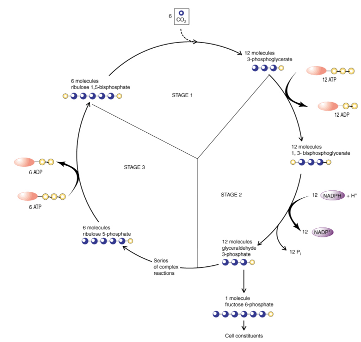


Figure 6.28