11

Catabolism: Energy Release and Conservation

11.1 Metabolic diversity and nutritional types

1. Use the terms that describe a microbe's carbon source, energy source, and electron source
2. State the carbon, energy, and electron sources of photolithoautotrophs, photoorganoheterotrophs, chemolithoautotrophs, chemolithoheterotrophs, and chemoorganoheterotrophs
3. Describe the products of the fueling reactions
4. Discuss the metabolic flexibility of microorganisms

Requirements for Carbon, Hydrogen, and Oxygen

- Often satisfied together
  - carbon source often provides H, O, and electrons
- Heterotrophs
  - use organic molecules as carbon sources which often also serve as energy source
  - can use a variety of carbon sources
- Autotrophs
  - use carbon dioxide as their sole or principal carbon source
  - must obtain energy from other sources

Nutritional Types of Organisms

- Based on energy source
  - phototrophs use light
  - chemotrophs obtain energy from oxidation of chemical compounds
- Based on electron source
  - lithotrophs use reduced inorganic substances
  - organotrophs obtain electrons from organic compounds

Table 11.1	Sources of Carbon, Energy, and Electrons
Carbon Sources	
Autotrophs	CO_2 sole or principal biosynthetic carbon source
Heterotrophs	Reduced, preformed, organic molecules from other organisms
Energy Sources	
Phototrophs	Light
Chemotrophs	Oxidation of organic or inorganic compounds
Electron Sources	
Lithotrophs	Reduced inorganic molecules
Organotrophs	Organic molecules

Classes of Major Nutritional Types

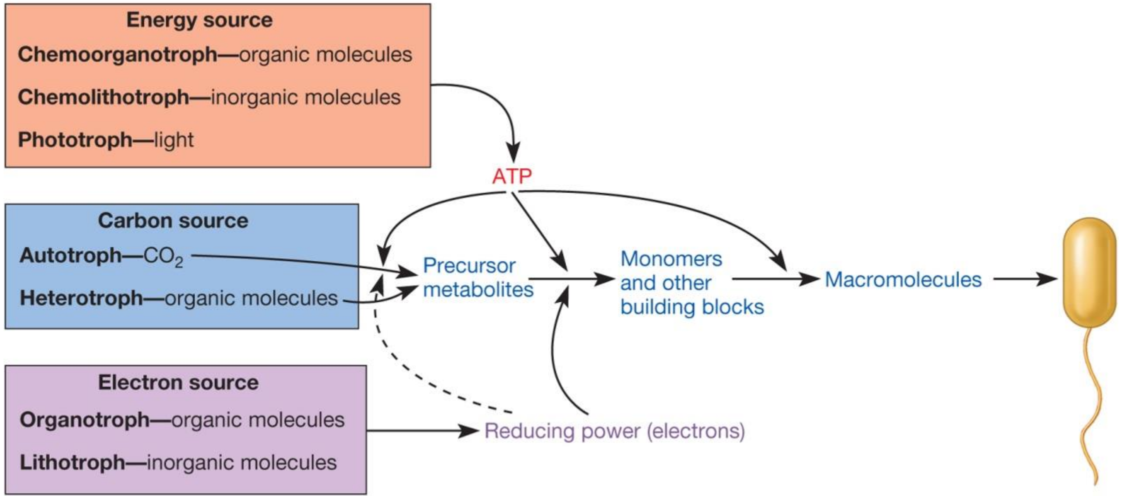
- Majority of microorganisms known
  - photolithoautotrophs (photoautotrophs)
  - chemoorganoheterotrophs (chemoheterotrophs)
    - majority of pathogens
- Ecological importance
  - photoorganoheterotrophs
  - chemolithoautotrophs
  - chemolithotrophs

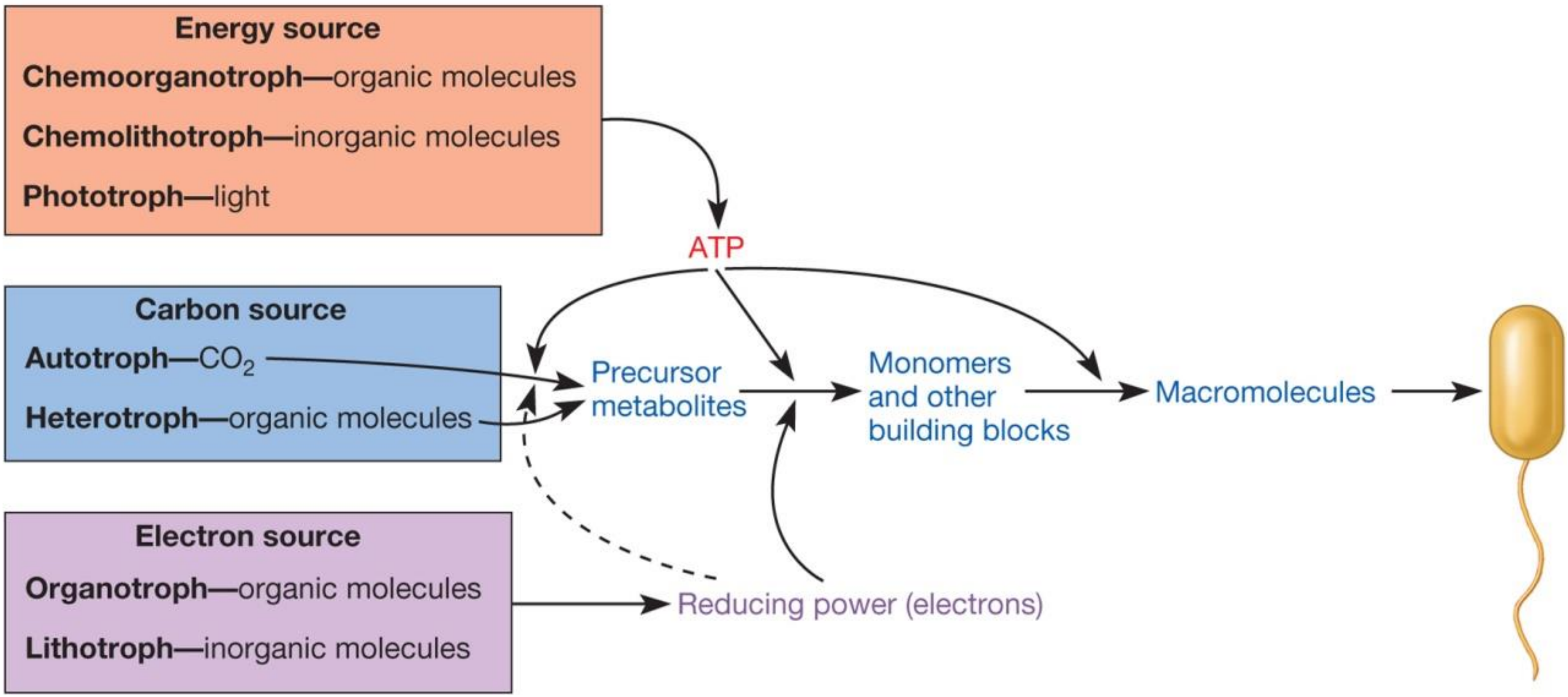
Table 11.2 Major Nutritional Types of Microorganisms

Nutritional Type	*Carbon Source*	*Energy Source*	*Electron Source*	*Representative Microorganisms*
Photolithoautotroph	CO_2	Light	Inorganic e^- donor	Purple and green sulfur bacteria, cyanobacteria, diatoms
Photoorganoheterotroph	Organic carbon	Light	Organic e^- donor	Purple nonsulfur bacteria, green nonsulfur bacteria
Chemolithoautotroph	CO_2	Inorganic chemicals	Inorganic e^- donor	Sulfur-oxidizing bacteria, hydrogen-oxidizing bacteria, methanogens, nitrifying bacteria, iron-oxidizing bacteria
Chemolithoheterotroph	Organic carbon	Inorganic chemicals	Inorganic e^- donor	Some sulfur-oxidizing bacteria (e.g., *Beggiatoa*)
Chemoorganoheterotroph	Organic carbon	Organic chemicals, often same as C source	Organic e^- donor, often same as C source	Most nonphotosynthetic microbes, including most pathogens, fungi, and many protists and archaea

Fueling Reactions

- Despite diversity of energy, electron, and carbon sources used by organisms, they all have the same basic needs
  - ATP as an energy currency
  - Reducing power to supply electrons for chemical reactions
  - Precursor metabolites for biosynthesis




Energy source
Chemoorganotroph—organic molecules
Chemolithotroph—inorganic molecules
Phototroph—light
ATP
Carbon source
Autotroph—CO_2
Heterotroph—organic molecules
Precursor metabolites
Monomers and other building blocks
Macromolecules
Electron source
Organotroph—organic molecules
Lithotroph—inorganic molecules
Reducing power (electrons)

Microorganisms May Change Nutritional Type

- Some have great metabolic flexibility based on environmental requirements
- Provides distinct advantage if environmental conditions change frequently

11.2 Chemoorganotrophic fueling processes

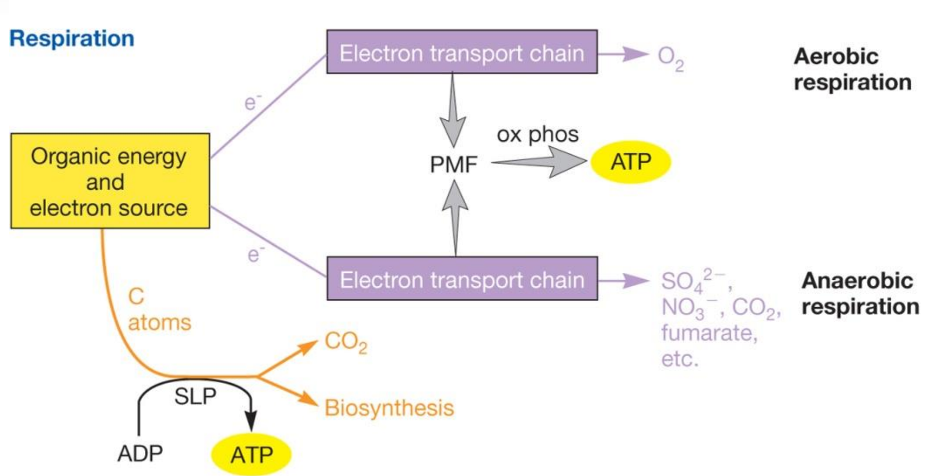
1. List the three types of chemoorganotrophic metabolisms
2. List the pathways of major importance to chemoorganotrophs and explain their importance
3. Propose an explanation that accounts for the existence of amphibolic pathways

Chemoorganotrophic Fueling Processes

- Also called chemoheterotrophs
- Processes
  - aerobic respiration
  - anaerobic respiration
  - fermentation

Chemoorganic Fueling Processes - Respiration - 1

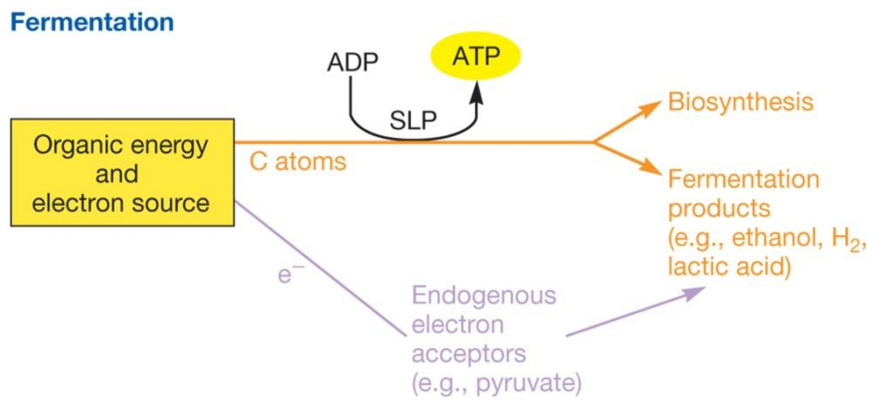
- Most respiration involves use of an electron transport chain
- As electrons pass through the electron transport chain to the final electron acceptor, a proton motive force (PMF) is generated and used to synthesize ATP



Chemoorganic Fueling Processes - Respiration - 2

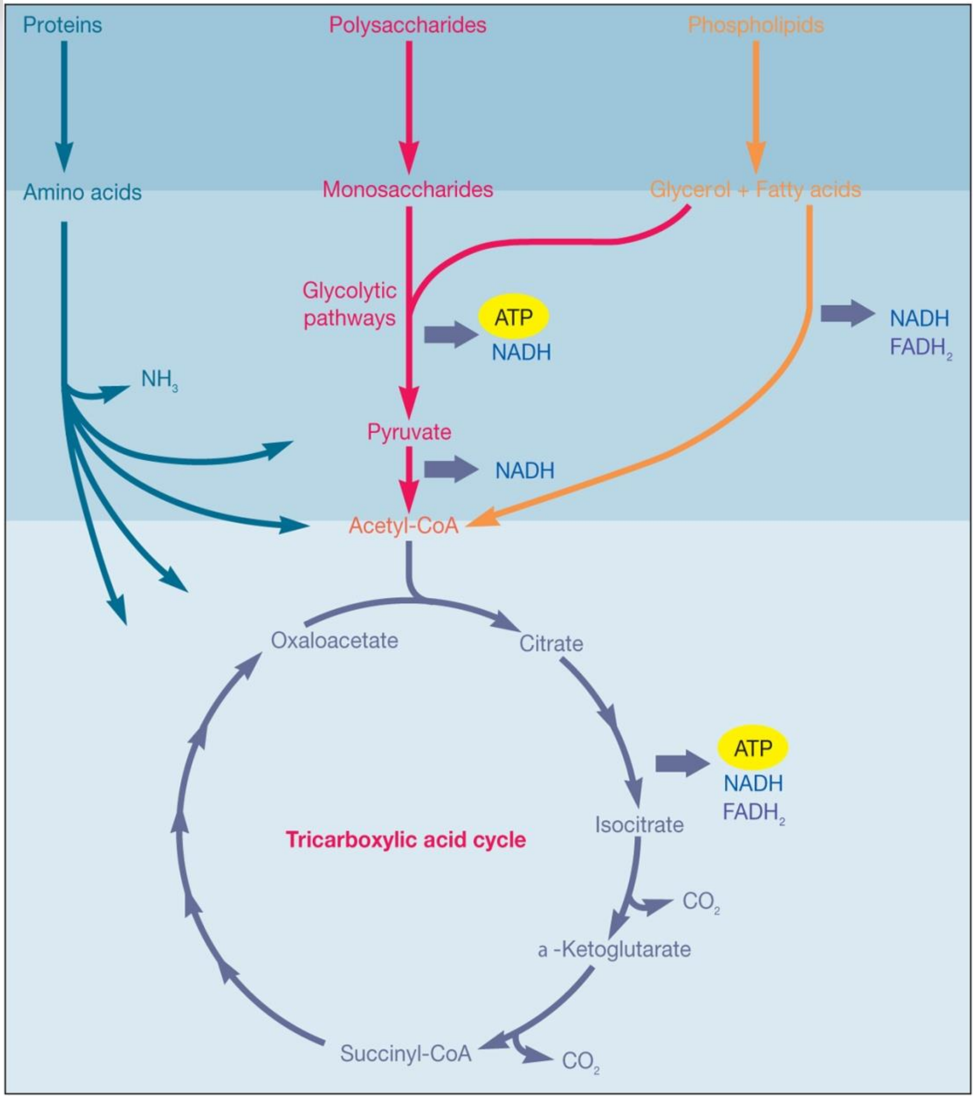
- aerobic respiration
  - final electron acceptor is oxygen
- anaerobic respiration
  - final electron acceptor is different exogenous acceptor such as
    - NO_3^-, SO_4^{2-}, CO_2, Fe^{3+}, or SeO_4^{2-}
  - organic acceptors may also be used
- ATP made primarily by oxidative phosphorylation

Chemoorganic Fueling Processes - Fermentation



- Uses an endogenous electron acceptor
  - usually an intermediate of the pathway used to oxidize the organic energy source e.g., pyruvate
- Does not involve the use of an electron transport chain nor the generation of a proton motive force
- ATP synthesized only by substrate-level phosphorylation

Energy Sources



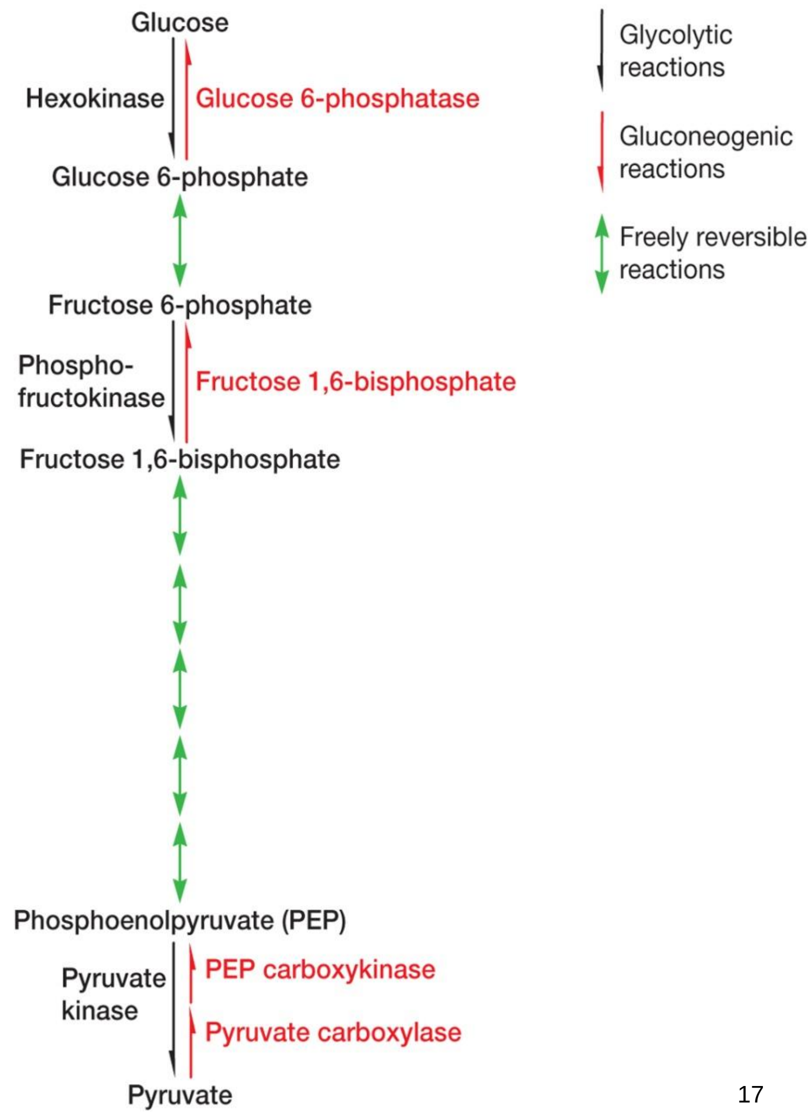
- Many different energy sources are funneled into common degradative pathways
- Most pathways generate glucose or intermediates of the pathways used in glucose metabolism
- Few pathways greatly increase metabolic efficiency

Catabolic Pathways

- Enzyme catalyzed reactions whereby the product of one reaction serves as the substrate for the next
- Pathways also provide materials for biosynthesis
- Amphibolic pathways

Amphibolic Pathways

- Function both as catabolic and anabolic pathways
- Important ones
  - Embden-Meyerhof pathway
  - pentose phosphate pathway
  - tricarboxylic acid (TCA) cycle



11.3 Aerobic respiration

1. Describe in general terms what happens to a molecule of glucose during aerobic respiration
2. List the end products made during aerobic respiration
3. Identify the process that generates the most ATP during aerobic respiration

Aerobic Respiration

- Process that can completely catabolize an organic energy source to CO_2 using
  - glycolytic pathways (glycolysis)
  - TCA cycle
  - electron transport chain with oxygen as the final electron acceptor
- Produces ATP (most of it indirectly via the activity of the electron transport chain), and high energy electron carriers

11.4 From glucose to pyruvate - 1

1. List the three major pathways that catabolize glucose to pyruvate
2. Describe substrate-level phosphorylation
3. Diagram the major changes made to glucose as it is catabolized by the Embden-Meyerhof, Entner-Duodoroff, and pentose phosphate pathways
4. Identify those reactions of the Embden-Meyerhof, Entner-Duodoroff, and pentose phosphate pathways that consume ATP, produce ATP and NAD(P)H, generate precursor metabolites, or are redox reactions

11.4 From glucose to pyruvate - 2

5. Calculate the yields of ATP and NAD(P)H by the Embden-Meyerhof, Entner-Duodoroff, and pentose phosphate pathways
6. Summarize the function of the Embden-Meyerhof, Entner-Duodoroff, and pentose phosphate pathways
7. Draw a simple diagram that shows the connection between, the Entner-Duodoroff pathway and the Embden-Meyerhof pathway and the connection between the pentose phosphate pathway and the Embden-Meyerhof pathway
8. Create a table that shows which types of organisms use each of the glycolytic pathways

The Breakdown of Glucose to Pyruvate

- Three common routes
  - Embden-Meyerhof pathway
  - pentose phosphate pathway
  - Entner-Duodoroff pathway

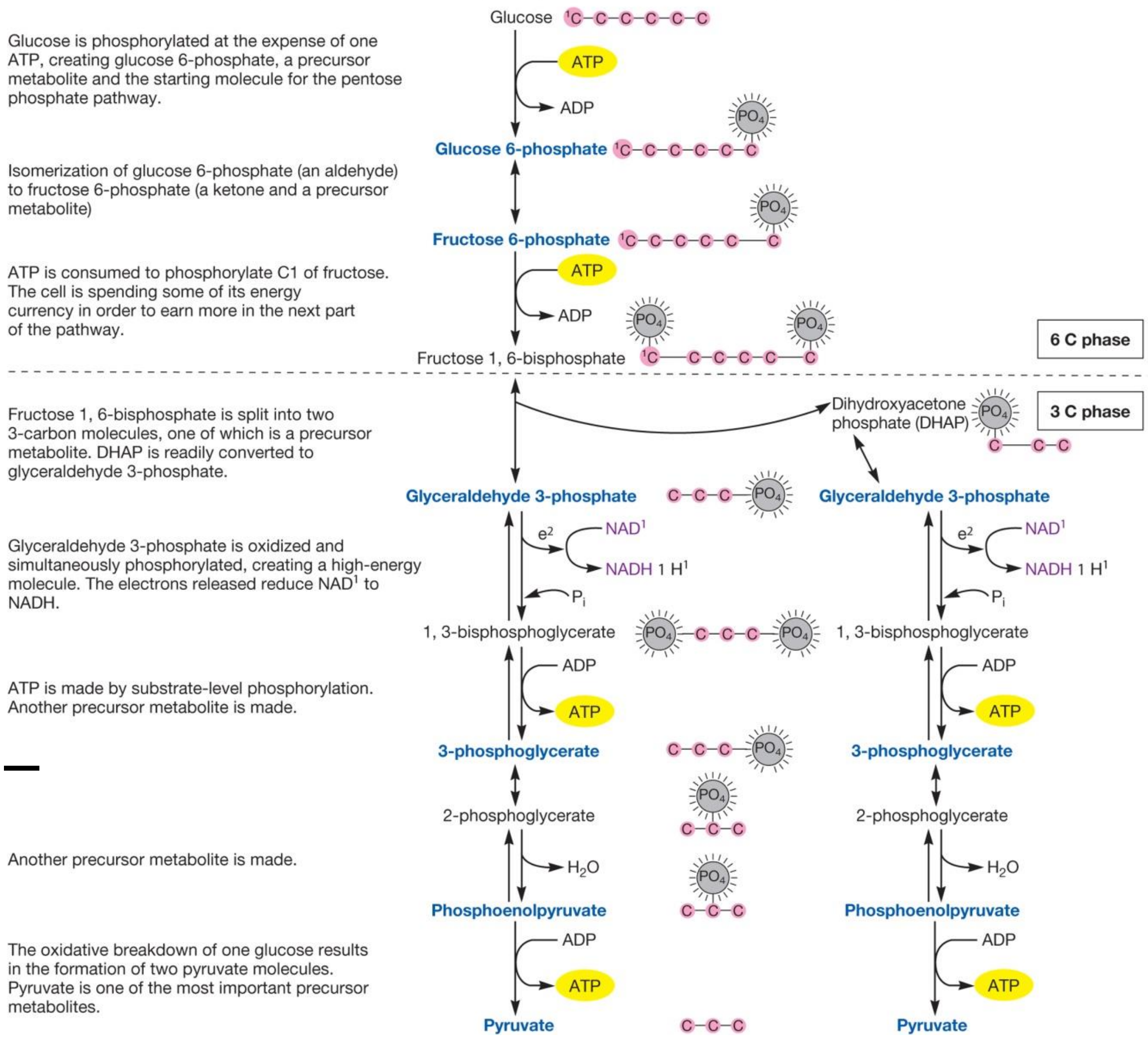
The Embden-Meyerhof Pathway

- Occurs in cytoplasmic matrix of most microorganisms, plants, and animals
- The most common pathway for glucose degradation to pyruvate in stage two of aerobic respiration
- Function in presence or absence of O_2
- Two phases
  - Six carbon phase
  - Three carbon phase

Addition of phosphates "primes the pump"

Oxidation step – generates NADH

High-energy molecules – used to synthesize ATP by substrate-level phosphorylation



Summary of Glycolysis

$$\text{glucose} + 2\text{ADP} + 2\text{P}_i + 2\text{NAD}^+$$

$$\downarrow$$

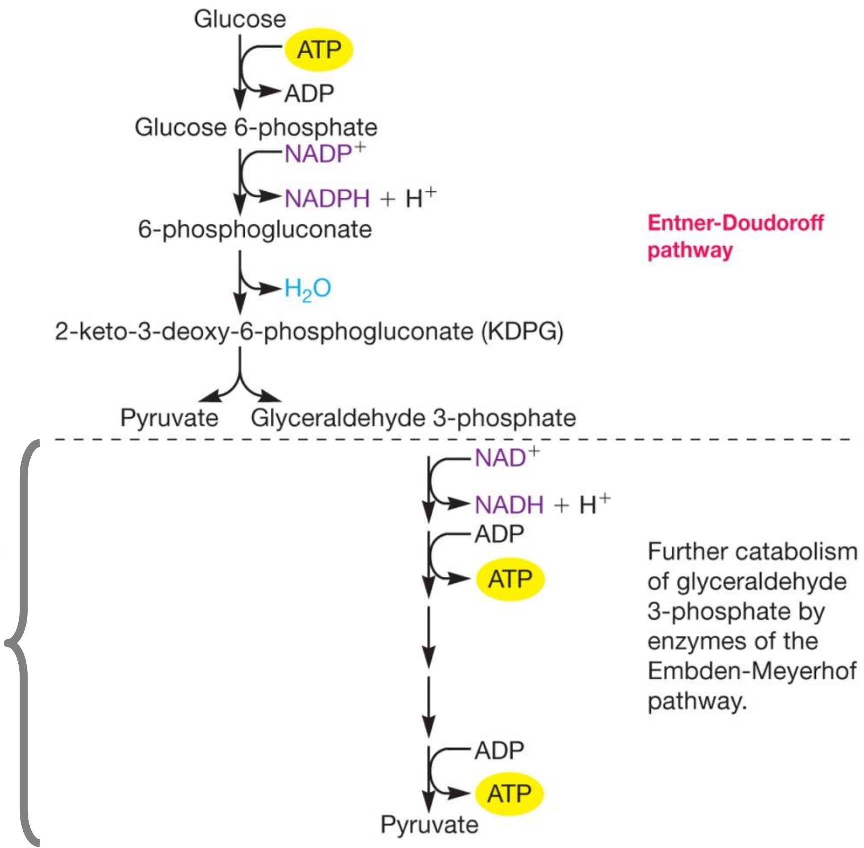
$$2\ \text{pyruvate} + 2\text{ATP} + 2\text{NADH} + 2\text{H}^+$$

The Entner-Duodoroff Pathway

- Used by soil bacteria and a few gram-negative bacteria
- Replaces the first phase of the Embden-Meyerhof pathway

- Yield per glucose molecule:
  - 1 ATP
  - 1 NADPH
  - 1 NADH

Reactions of glycolytic pathway

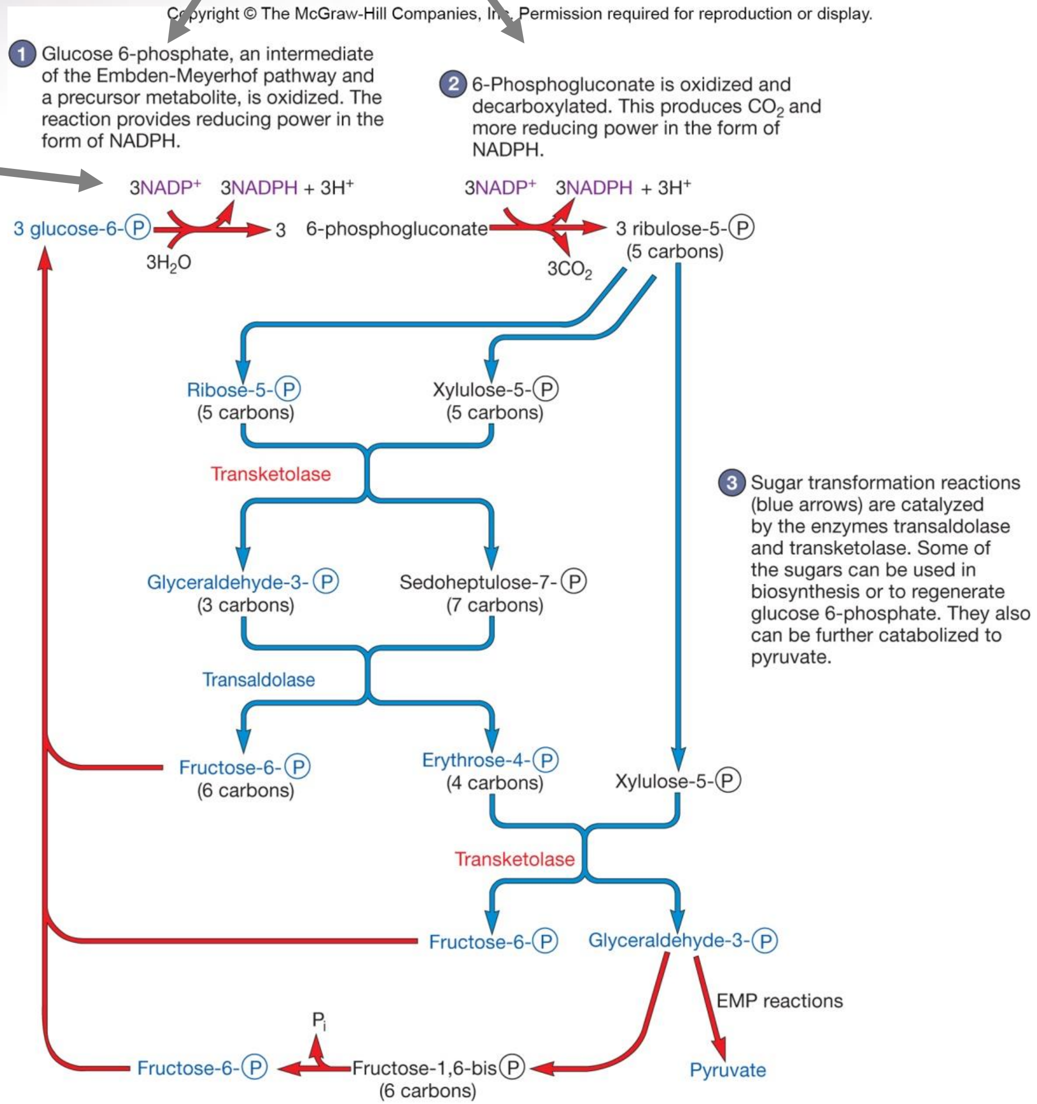


The Pentose Phosphate Pathway

- Also called hexose monophosphate pathway
- Can operate at same time as glycolytic pathway or Entner-Duodoroff pathway
- Can operate aerobically or anaerobically
- An amphibolic pathway

Oxidation steps

Produce NADPH, which is needed for biosynthesis



Sugar trans-formation reactions

Produce sugars needed for biosynthesis

Sugars can also be further degraded

Summary of Pentose Phosphate Pathway

glucose-6-P + 12NADP$^+$ + 7H_2O

$\downarrow$

6CO_2 + 12NADPH + 12H$^+$ P_i

11.5 Tricarboxylic acid cycle - 1

1. State the alternate names for the tricarboxylic acid (TCA) cycle
2. Diagram the major changes made to pyruvate as it is catabolized by the TCA cycle
3. Identify those reactions of the TCA cycle that produce ATP (or GTP) and NAD(P)H, generate precursor metabolites, or are redox reactions
4. Calculate the yields of ATP (or GTP), NAD(P)H, and $FADH_2$ by the TCA cycle

11.5 Tricarboxylic acid cycle - 2

5. Summarize the function of the TCA cycle
6. Diagram the connections between the various glycolytic pathways and the TCA cycle
7. Locate the TCA cycle enzymes in bacterial, archaeal, and eukaryotic cells

11.6 Electron transport and oxidative phosphorylation - 1

1. Compare and contrast the mitochondrial electron transport chain (ETC) and bacterial ETCs
2. Describe the chemiosmotic hypothesis
3. Correlate length of an ETC and the carriers in it with the strength of the proton motive force (PMF) it generates
4. Explain how ATP synthase uses PMF to generate ATP

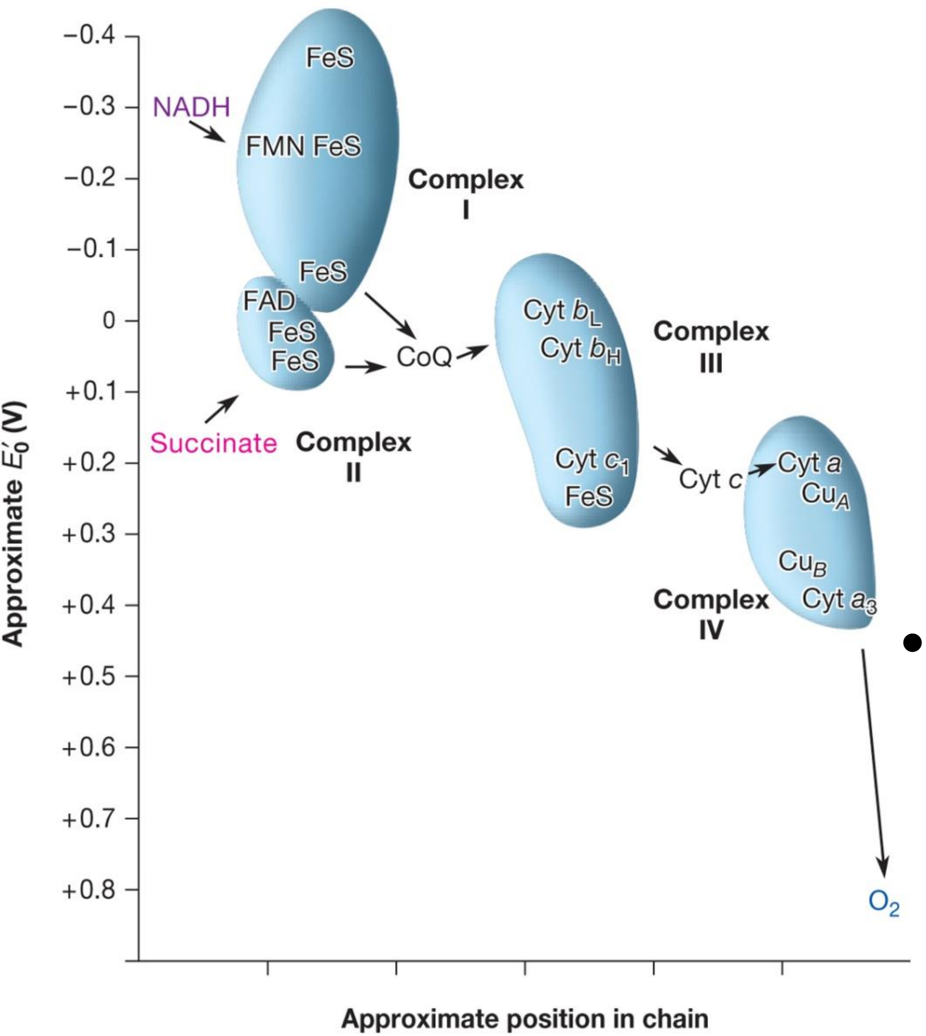
11.6 Electron transport and oxidative phosphorylation - 2

5. Draw a simple diagram that shows the connections between the glycolytic pathways, TCA cycle, ETC, and ATP synthesis
6. List uses for the PMF generated by bacterial cells in addition to ATP synthesis
7. Calculate the maximum possible ATP yields when glucose is completely catabolized to six molecules of CO_2 during aerobic respiration

Electron Transport and Oxidative Phosphorylation

- Only 4 ATP molecules synthesized directly from oxidation of glucose to CO_2
- Most ATP made when NADH and $FADH_2$ (formed as glucose degraded) are oxidized in electron transport chain (ETC)

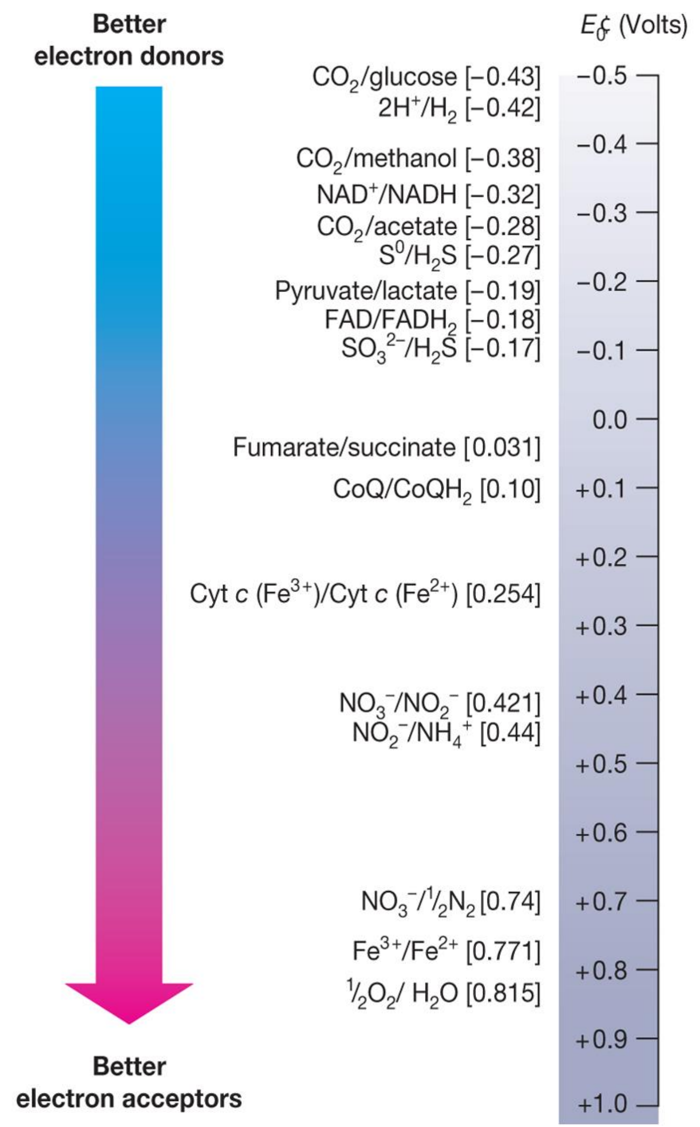
Electron Transport Chains



- The mitochondrial electron transport chain (ETC) = a series of e^- carriers, operating together to transfer e^- from NADH and $FADH_2$ to a terminal e^- acceptor, O_2
- E^- flow from carriers with more negative reduction potentials (E_0) to carriers with more positive E_0

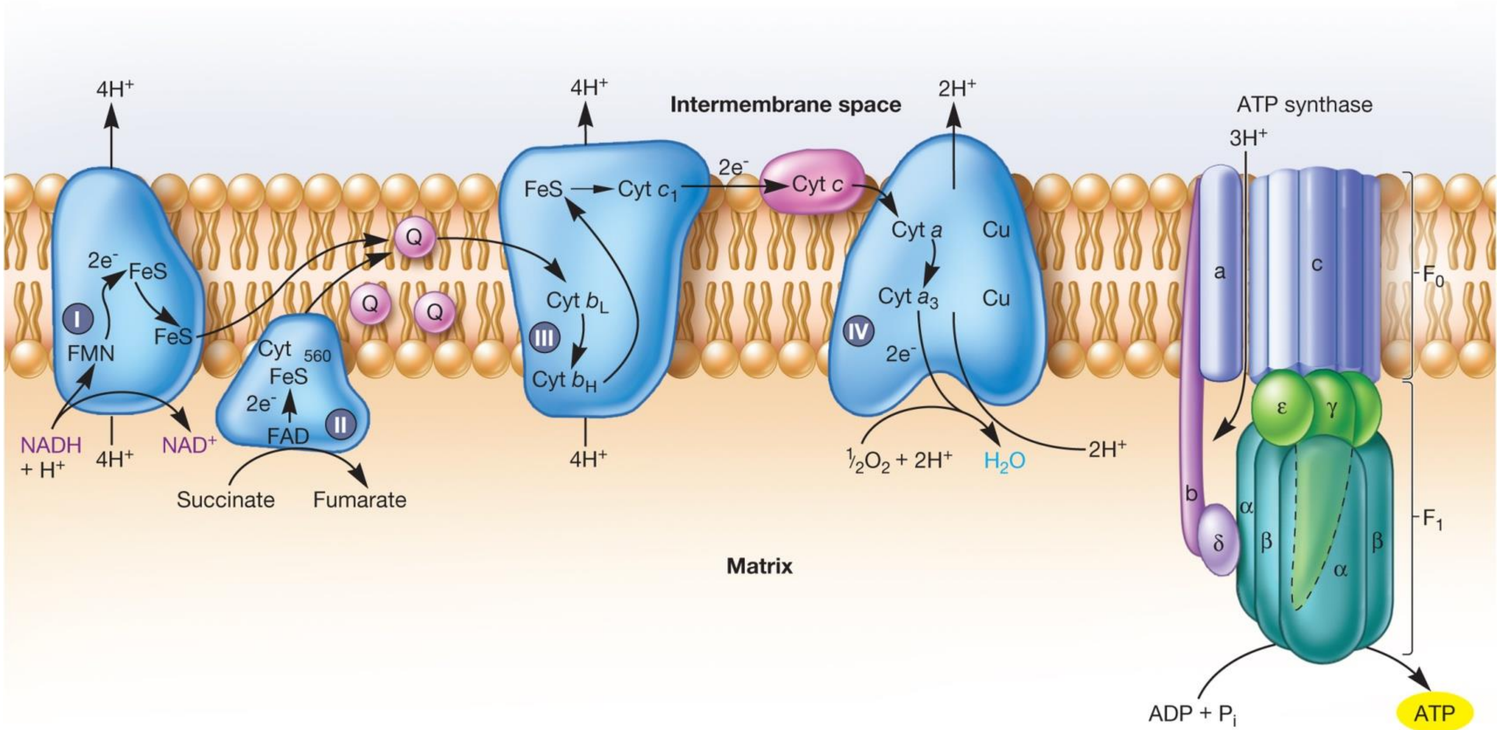
Electron Transport Chain

- Each carrier is reduced and then reoxidized
- Carriers are constantly recycled
- The difference in reduction potentials electron carriers, NADH and O_2 is large, resulting in release of great deal of energy



Electron Transport Chain…

- In eukaryotes the e^- transport chain carriers are in the inner mitochondrial membrane, connected by coenzyme Q and cytochrome c
- E^- transfer accompanied by proton movement across inner mitochondrial membrane

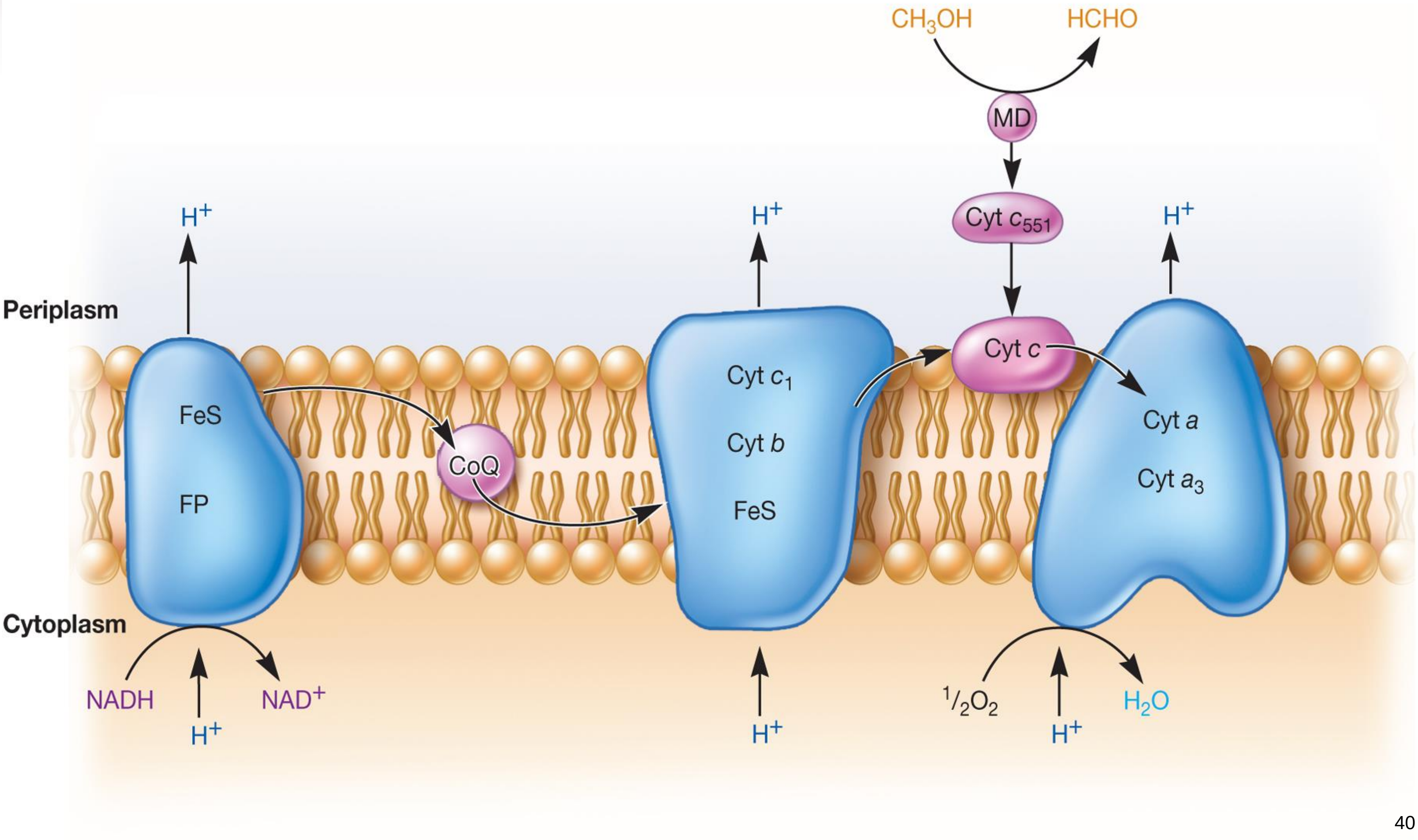


Bacterial and Archaeal ETCs

- Located in plasma membrane
- Some resemble mitochondrial ETC, but many are different
  - different electron carriers
  - may be branched
  - may be shorter
  - may have lower P/O ratio

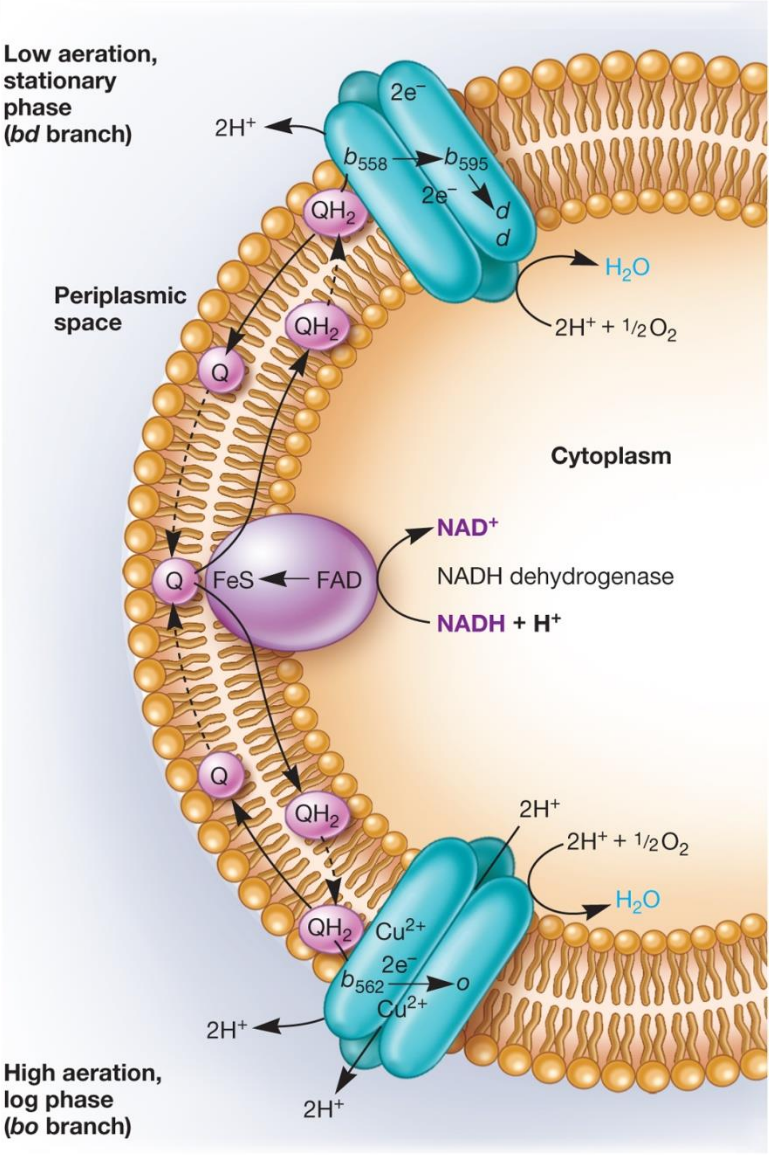
Paracoccus denitrificans

- Facultative, soil bacterium
- Extremely versatile metabolically
- Under oxic conditions, uses aerobic respiration
  - similar electron carriers and transport mechanism as mitochondria
  - protons transported to periplasmic space rather than inner mitochondrial membrane
  - can use one carbon molecules instead of glucose


CH3OH
HCHO
MD
Cyt c551
H+
H+
H+
Periplasm
Cyt c
FeS
Cyt c1
Cyt b
FeS
CoQ
FP
Cyt a
Cyt a3
Cytoplasm
NADH
H+
NAD+
H+
1/2O2
H+
H2O

Electron Transport Chain of *E. coli*

Different array of cytochromes used than in mitochondrial



Branched pathway

Upper branch – stationary phase and low aeration

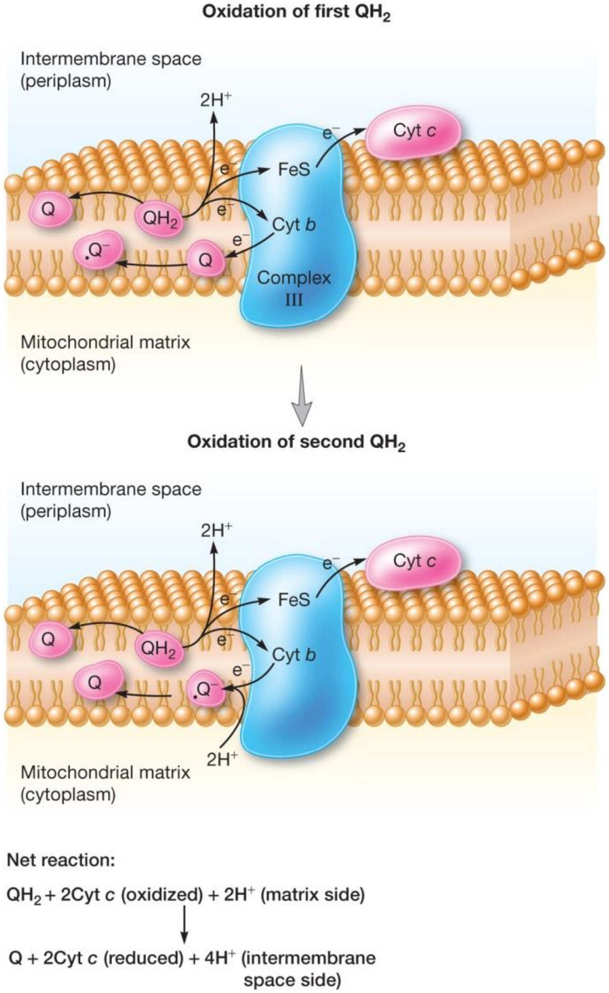
Lower branch – log phase and high aeration

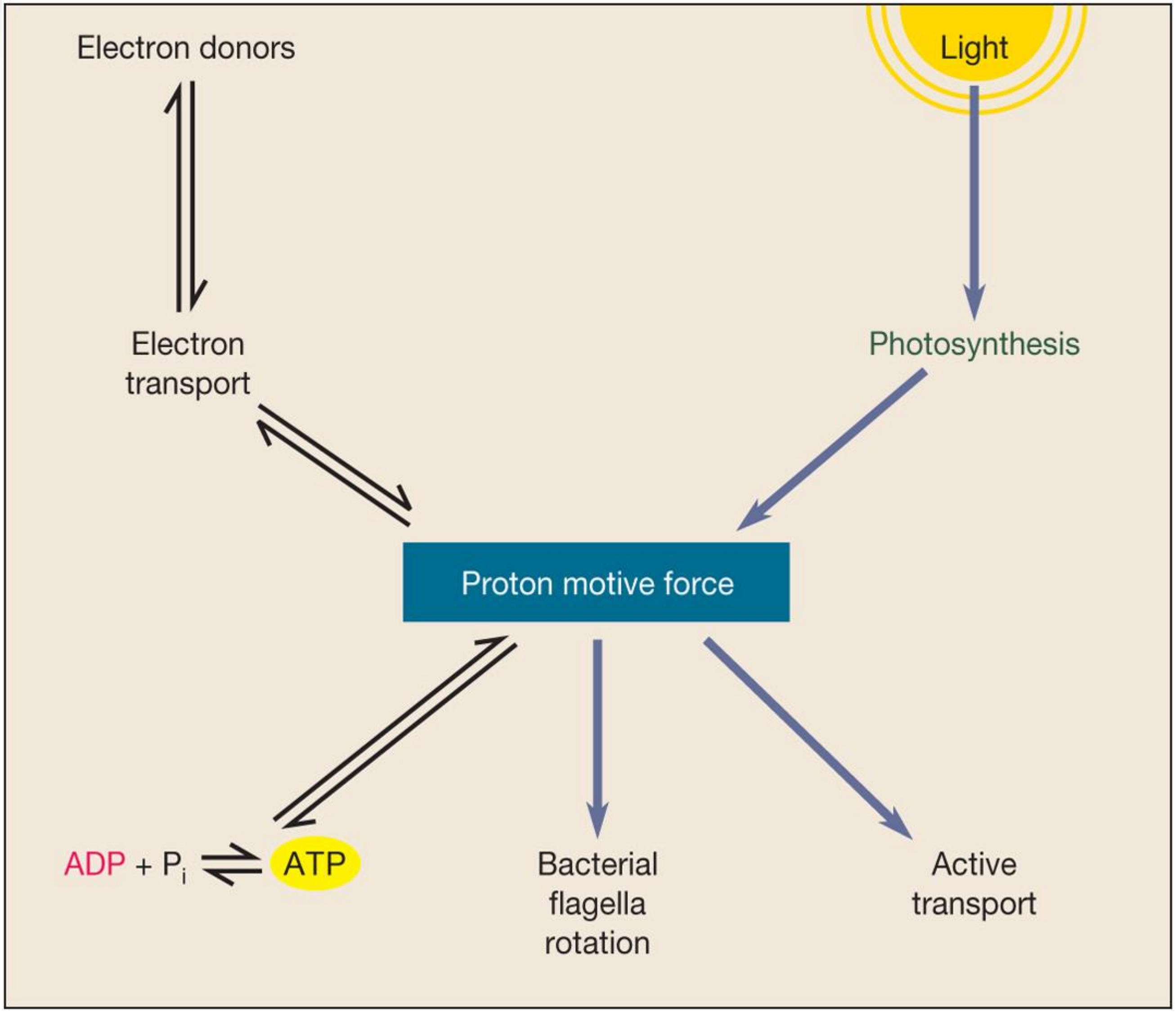
Oxidative Phosphorylation

- Process by which ATP is synthesized as the result of electron transport driven by the oxidation of a chemical energy source

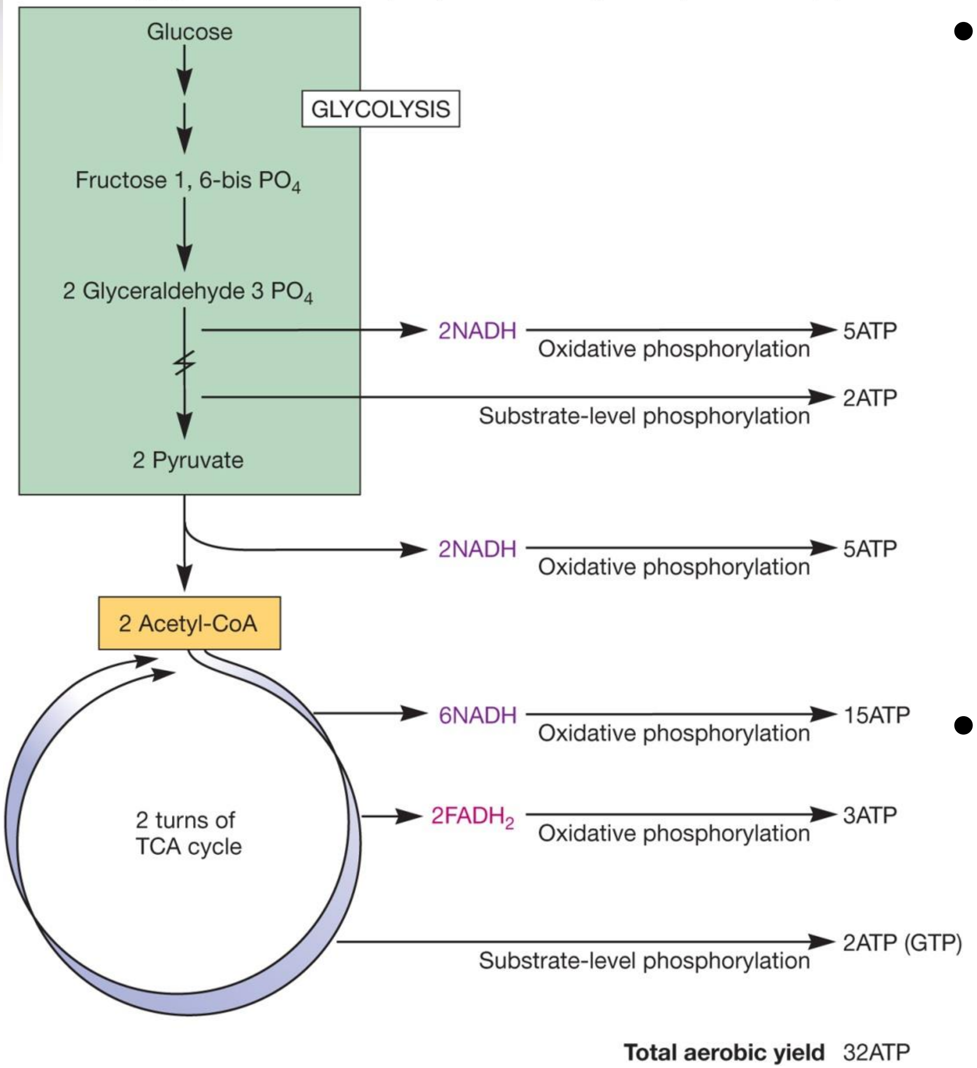
Chemiosmotic Hypothesis

- The most widely accepted hypothesis to explain oxidative phosphorylation
  - protons move outward from the mitochondrial matrix as e$^-$ are transported down the chain
  - proton expulsion during e$^-$ transport results in the formation of a concentration gradient of protons and a charge gradient
  - the combined chemical and electrical potential difference make up the proton motive force (PMF)




Electron donors
Light
Electron transport
Photosynthesis
Proton motive force
ADP + P_i ⇌ ATP
Bacterial flagella rotation
Active transport

ATP Yield During Aerobic Respiration



- Maximum ATP yield can be calculated
  - includes P/O ratios of NADH and $FADH_2$
  - ATP produced by substrate level phosphorylation
- The theoretical maximum total yield of ATP during aerobic respiration is 38
  - the actual number closer to 30 than 38

Theoretical vs. Actual Yield of ATP

- Amount of ATP produced during aerobic respiration varies depending on growth conditions and nature of ETC
- Under anaerobic conditions, glycolysis only yields 2 ATP molecules

Factors Affecting ATP Yield

- Bacterial ETCs are shorter and have lower P/O ratios
- ATP production may vary with environmental conditions
- PMF in bacteria and archaea is used for other purposes than ATP production (flagella rotation)
- Precursor metabolite may be used for biosynthesis

11.7 Anaerobic respiration

1. Compare and contrast aerobic respiration and anaerobic respiration using glucose as carbon source
2. List examples of terminal electron acceptors used during anaerobic respiration
3. Defend this statement: “The use of nitrate (NO_3^-) as a terminal electron acceptor is dissimilatory nitrate reduction.”
4. Predict the relative amount of energy released for each of the common terminal electron acceptors used during anaerobic respiration, as compared to energy released during aerobic respiration
5. List three examples of the importance of anaerobic respiration

Anaerobic Respiration

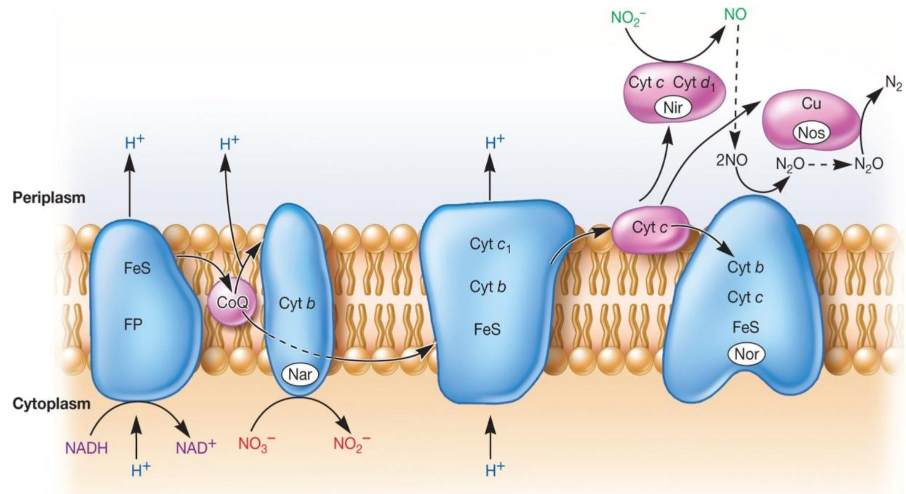
- Uses electron carriers other than O_2
- Generally yields less energy because E_0 of electron acceptor is less positive than E_0 of O_2

Table 11.3 Some Electron Acceptors Used in Respiration

	Electron Acceptor	Reduced Products	Examples of Microorganisms
Aerobic	O_2	H_2O	All aerobic bacteria, fungi, and protists
Anaerobic	NO_3^-	NO_2^-	Enteric bacteria
	NO_3^-	NO_2^-, N_2O, N_2	*Pseudomonas*, *Bacillus*, and *Paracoccus*
	SO_4^{2-}	H_2S	*Desulfovibrio* and *Desulfotomaculum*
	CO_2	CH_4	Methanogens
	CO_2	Acetate	Acetogens
	S^0	H_2S	*Desulfuromonas* and *Thermoproteus*
	Fe^{3+}	Fe^{2+}	*Pseudomonas*, *Bacillus*, and *Geobacter*
	$HAsO_4^{2-}$	$HAsO_2$	*Bacillus*, *Desulfotomaculum*, *Sulfurospirillum*
	SeO_4^{2-}	Se, $HSeO_3^-$	*Aeromonas*, *Bacillus*, *Thauera*
	Fumarate	Succinate	*Wolinella*

An Example…

- Dissimilatory nitrate reduction
  - use of nitrate as terminal electron acceptor, making it unavailable to cell for assimilation or uptake
- Denitrification
  - reduction of nitrate to nitrogen gas
  - in soil, causes loss of soil fertility

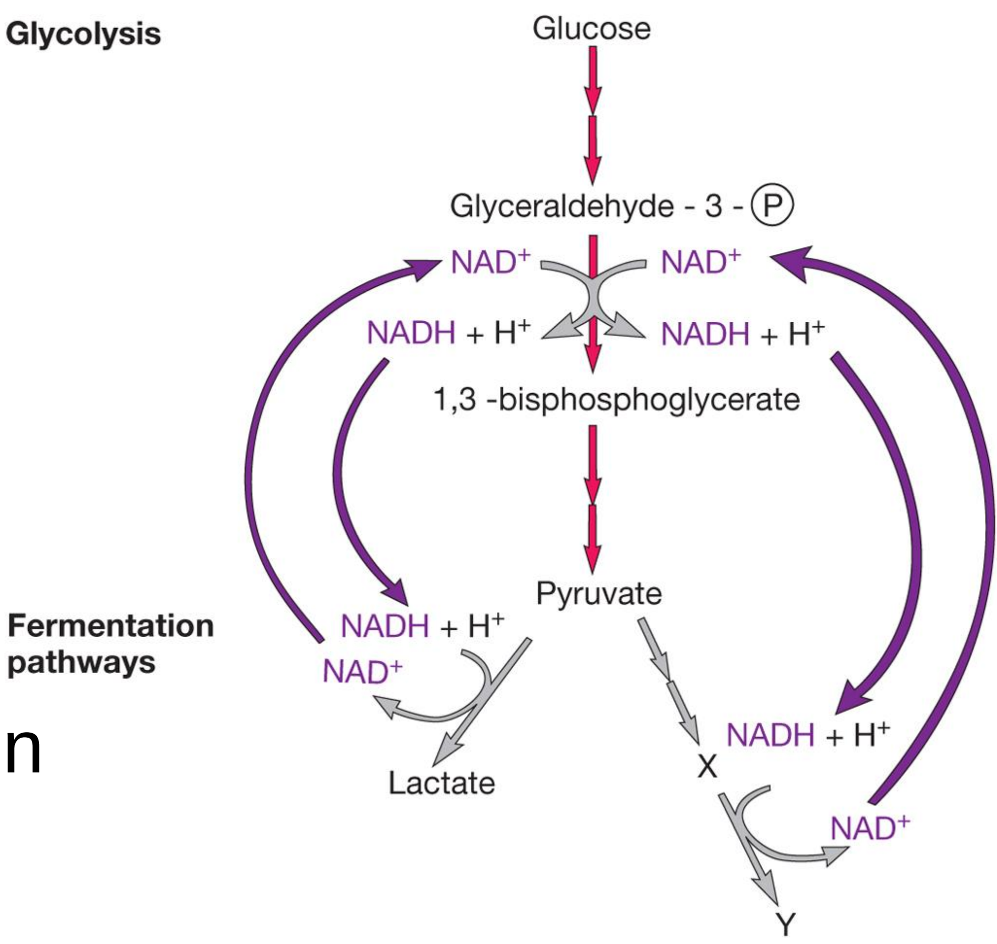


11.8 Fermentation

1. Compare and contrast aerobic respiration, anaerobic respiration, and fermentation of glucose
2. List the pathways that may function during fermentation if glucose is the organism's carbon and energy source
3. Create a table that lists some of the common fermentation pathways and their products, and gives examples of their importance
4. Compare the use of ATP synthase during respiration and fermentation

Fermentation

- Oxidation of NADH produced by glycolysis
- Pyruvate or derivative used as endogenous electron acceptor
- Substrate only partially oxidized
- Oxygen not needed
- Oxidative phosphorylation does not occur
  – ATP formed by substrate-level phosphorylation



Homolactic fermenters

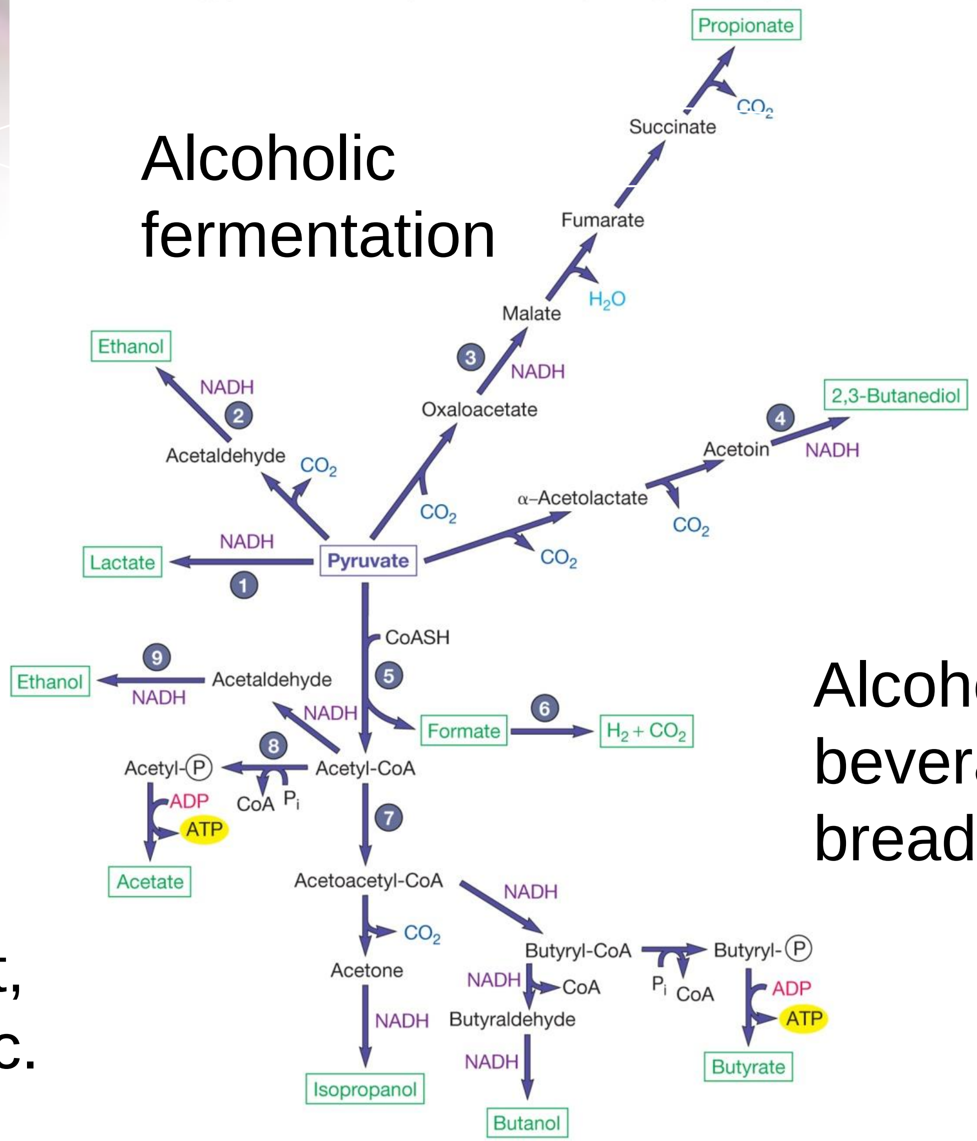
Alcoholic fermentation

Heterolactic fermenters

Food spoilage

Yogurt, sauerkraut, pickles, etc.

Alcoholic beverages, bread, etc.



1. Lactic acid bacteria (*Streptococcus*, *Lactobacillus*), *Bacillus*, enteric bacteria (*Escherichia*, *Enterobacter*, *Salmonella*, *Proteus*)
2. Yeast, *Zymomonas*
3. Propionic acid bacteria (*Propionibacterium*)
4. *Enterobacter*, *Serratia*, *Bacillus*
5. Enteric bacteria
6. Enteric bacteria
7. *Clostridium*
8. Enteric bacteria
9. Enteric bacteria

Table 11.4 Mixed Acid Fermentation Products of *Escherichia coli*

	FERMENTATION BALANCE (μM PRODUCT/100 μM GLUCOSE)	
	Acid Growth (pH 6.0)	Alkaline Growth (pH 8.0)
Ethanol	50	50
Formic acid	2	86
Acetic acid	36	39
Lactic acid	80	70
Succinic acid	11	15
Carbon dioxide	88	2
Hydrogen gas	75	0.5

11.10 Chemolithotrophy

1. Describe in general terms the fueling reactions of chemolithotrophs
2. List the molecules commonly used as energy sources and electron donors by chemolithotrophs
3. Discuss the use of electron transport chains and oxidative phosphorylation by chemolithotrophs

Chemolithotrophy

- Carried out by chemolithotrophs
- E^- released from energy source which is an inorganic molecule
  - transferred to terminal e^- acceptor by ETC
- ATP synthesized by oxidative phosphorylation

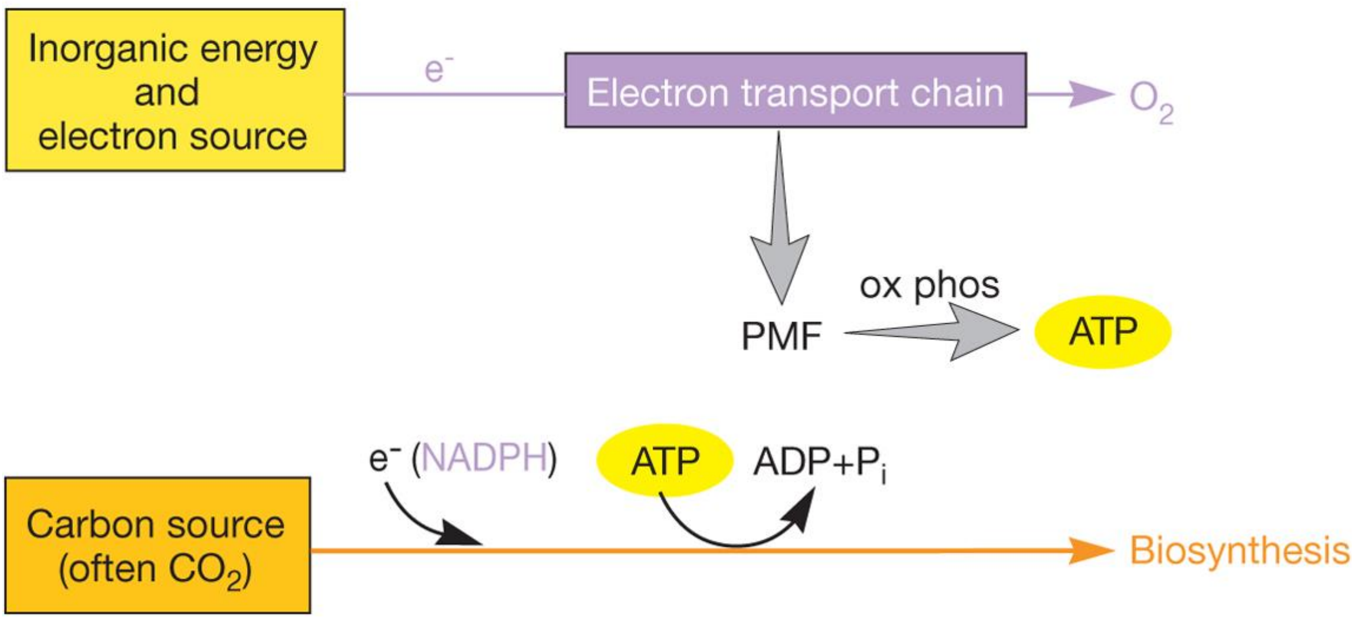


Table 11.5 Representative Chemolithotrophs and Their Energy Sources

Bacteria	Electron Donor	Electron Acceptor	Products
Alcaligenes, Hydrogenophaga, and *Pseudomonas* spp.	H_2	O_2	H_2O
Nitrobacter	NO_2^-	O_2	NO_3^-, H_2O
Nitrosomonas	NH_4^+	O_2	NO_2^-, H_2O
Thiobacillus denitrificans	S^0, H_2S	NO_3^-	SO_4^{2-}, N_2
Acidithiobacillus ferrooxidans	Fe^{2+}, S^0, H_2S	O_2	Fe^{3+}, H_2O, H_2SO_4

Energy Sources

Table 11.6 Energy Yields from Oxidations Used by Chemolithotrophs

Reaction	$\Delta G^{\circ\prime}$ (kcal/mole)[1]
$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$	−56.6
$NO_2^- + \frac{1}{2}O_2 \rightarrow NO_3^-$	−17.4
$NH_4^+ + 1\frac{1}{2}O_2 \rightarrow NO_2^- + H_2O + 2H^+$	−65.0
$S^0 + 1\frac{1}{2}O_2 + H_2O \rightarrow H_2SO_4$	−118.5
$S_2O_3^{2-} + 2O_2 + H_2O \rightarrow 2SO_4^{2-} + 2H^+$	−223.7
$2Fe^{2+} + 2H^+ + \frac{1}{2}O_2 \rightarrow 2Fe^{3+} + H_2O$	−11.2

1 The $\Delta G^{\circ\prime}$ for complete oxidation of glucose to CO_2 is −686 kcal/mole. A kcal is equivalent to 4.184 kJ.

- Bacterial and archaeal species have specific electron donor/acceptor preferences
- Much less energy is available from oxidation of inorganic molecules than glucose oxidation due to more positive redox potentials

Three Major Groups of Chemolithotrophs

- Have ecological importance
- Several bacteria and archaea oxidize hydrogen
- Sulfur-oxidizing microbes
  - hydrogen sulfide (H_2S), sulfur (S^0), thiosulfate ($S_2O_3^{2-}$)
- Nitrifying bacteria oxidize ammonia to nitrate

Sulfur-Oxidizing Bacteria

(a) Direct oxidation of sulfite

$$SO_3^{2-} \xrightarrow{\text{sulfite oxidase}} SO_4^{2-} + 2e^-$$

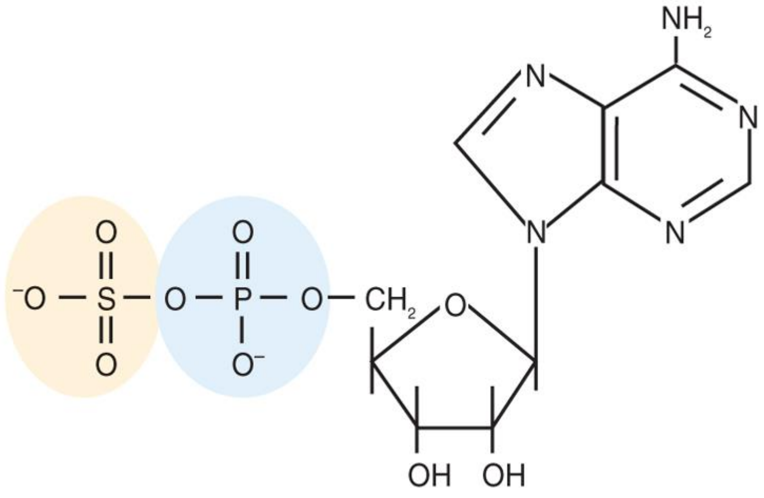
(b) Formation of adenosine 5′-phosphosulfate

$$2SO_3^{2-} + 2AMP \longrightarrow 2APS + 4e^-$$

$$2APS + 2P_i \longrightarrow 2ADP + 2SO_4^{2-}$$

$$2ADP \longrightarrow AMP + ATP$$

$$2SO_3^{2-} + AMP + 2P_i \longrightarrow 2SO_4^{2-} + ATP + 4e^-$$

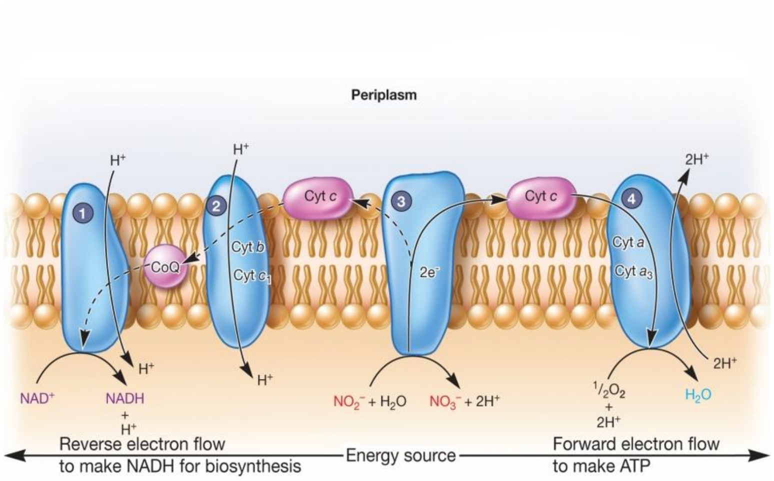


(c) Adenosine 5′-phosphosulfate

*ATP can be synthesized by both oxidative phosphorylation and substrate-level phosphorylation

Reverse Electron Flow by Chemolithotrophs

- Calvin cycle requires NAD(P)H as e^- source for fixing CO_2
  - many energy sources used by chemolithotrophs have E_0 more positive than $NAD^+(P)/NAD(P)H$
    - use reverse electron flow to generate NAD(P)H



When *Nitrobacter* needs to make more NADH, reverse electron flow is used. This is done at the expense of the PMF. Notice that protons are moving from the periplasm to the cytoplasm.

When *Nitrobacter* needs to synthesize ATP, electrons flow in a forward direction and generate PMF. Notice that protons are being moved across the membrane by the cytochrome aa_3 oxidase.

Metabolic Flexibility of Chemolithotrophs

- Many switch from chemolithotrophic metabolism to chemoorganotrophic metabolism
- Many switch from autotrophic metabolism (via Calvin cycle) to heterotrophic metabolism

11.11 Phototrophy - 1

1. Describe in general terms the fueling reactions of phototrophs
2. Differentiate phototrophy from photosynthesis
3. Describe the light and dark reactions that occur during photosynthesis
4. Summarize the structure and function of the light-absorbing pigments used by oxygenic and anoxygenic phototrophs

11.11 Phototrophy - 2

1. Defend this statement: “Oxidative phosphorylation and photophosphorylation by chlorophyll-based phototrophs differ primarily in the energy source driving the process.”
2. Distinguish cyclic photophosphorylation from noncyclic photophosphorylation.
3. Compare and contrast oxygenic photosynthesis, anoxygenic phototrophy, and rhodopsin-based phototrophy
4. List two examples of the importance of chlorophyll-based phototrophy

Phototrophy

Table 11.7	Diversity of Phototrophic Microorganisms
Eukaryotes	Multicellular green, brown, and red algae; unicellular protists (e.g., euglenoids, dinoflagellates, diatoms)
Bacteria	Cyanobacteria, green sulfur bacteria, green nonsulfur bacteria, purple sulfur bacteria, purple nonsulfur bacteria, heliobacteria, acidobacteria
Archaea	Halophiles

- Photosynthesis
  - energy from light trapped and converted to chemical energy
  - a two-part process
    - light reactions: light energy is trapped and converted to chemical energy
    - dark reactions: energy produced in the light reactions is used to reduce CO_2 and synthesize cell constituents

Light Reactions in Oxygenic Photosynthesis

- Photosynthetic eukaryotes and cyanobacteria
- Oxygen is generated and released into the environment
- Most important pigments are chlorophylls

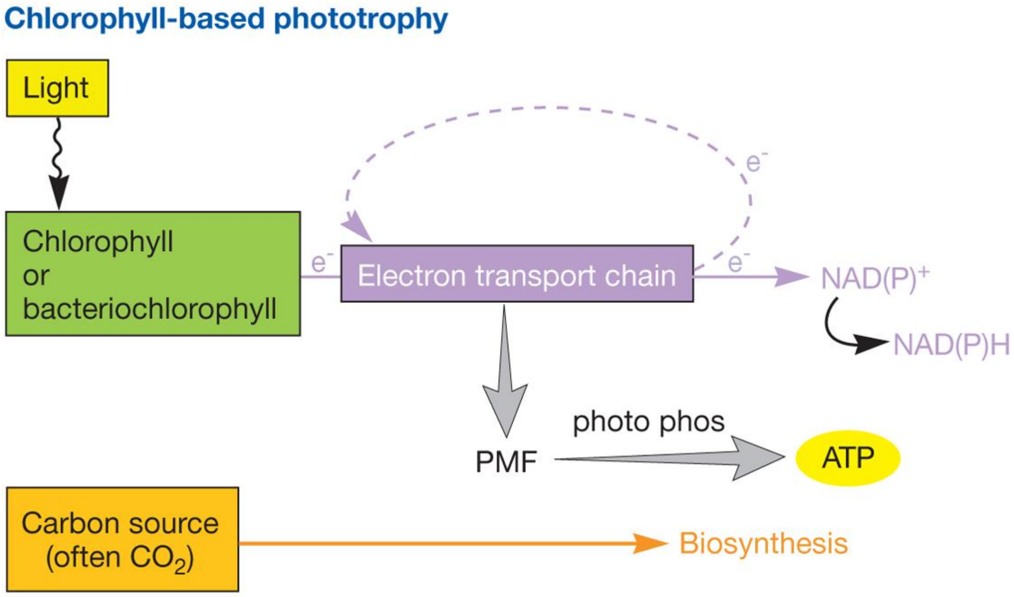


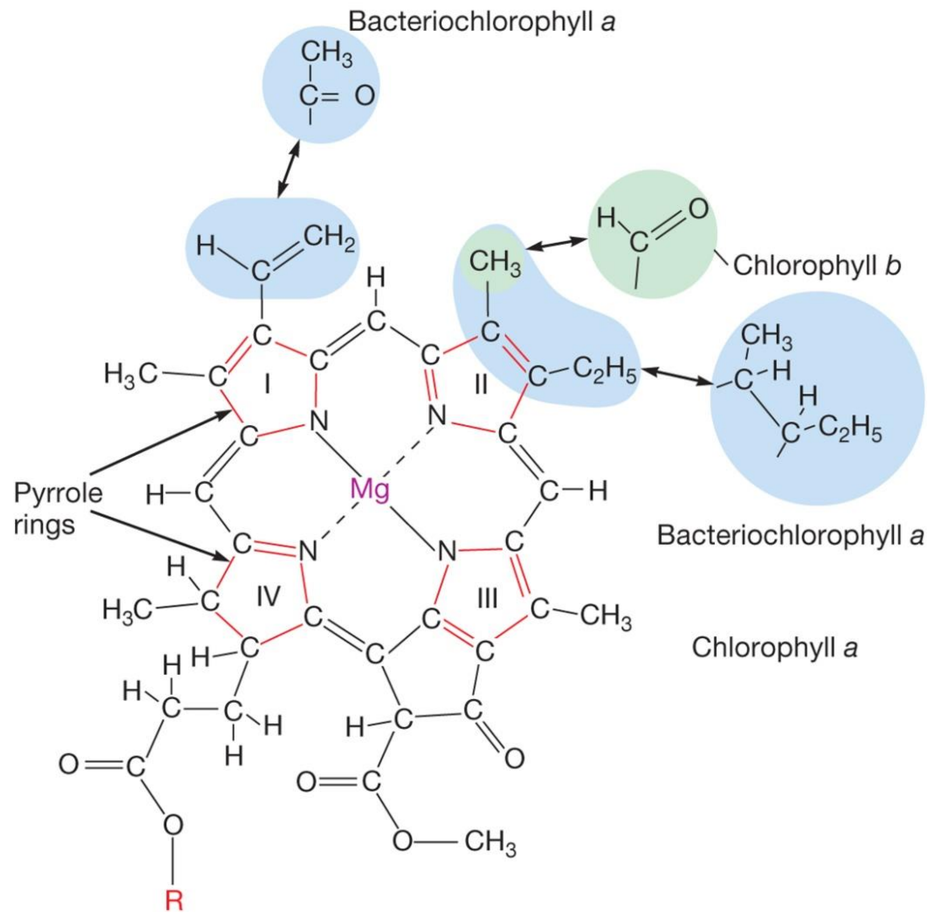
Table 11.8 Properties of Chlorophyll-Based Photosynthetic Systems

Property	Eukaryotes	Cyanobacteria	Green Bacteria, Purple Bacteria, Heliobacteria, and Acidobacteria
Photosynthetic pigment	Chlorophyll *a*	Chlorophyll *a*[1]	Bacteriochlorophyll
Number of photosystems	2	2[2]	1
Photosynthetic electron donors	H_2O	H_2O	H_2, H_2S, S, organic matter
O_2 production pattern	Oxygenic	Oxygenic[3]	Anoxygenic
Primary products of energy conversion	ATP + NADPH	ATP + NADPH	ATP
Carbon source	CO_2	CO_2	Organic or CO_2

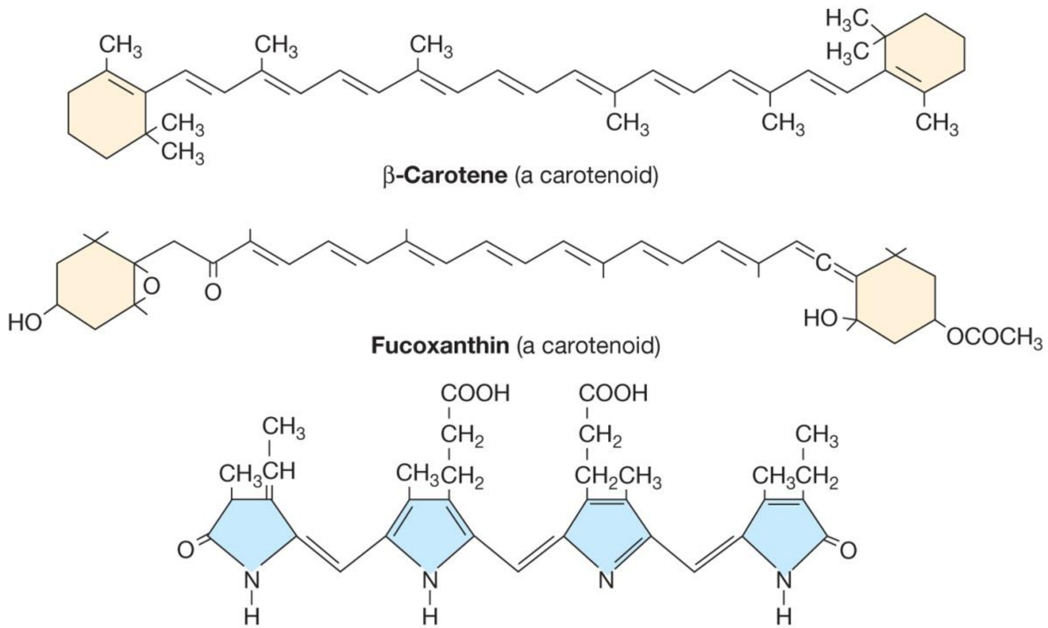
1 Members of the cyanobacterial genus *Prochlorococcus* have divinyl chlorophyll *a* and *b*.
2 A recently discovered cyanobacterium lacks photosystem II.
3 Some cyanobacteria can function anoxygenically under certain conditions. For example, *Oscillatoria* can use H_2S as an electron donor instead of H_2O.

The Light Reaction in Oxygenic Photosynthesis

- Chlorophylls
  - major light-absorbing pigments
  - different chlorophylls have different absorption peaks



The Light Reaction in Oxygenic Photosynthesis



- Accessory pigments
  - transfer light energy to chlorophylls
  - e.g., carotenoids and phycobiliproteins
  - accessory pigments absorb different wavelengths of light than chlorophylls

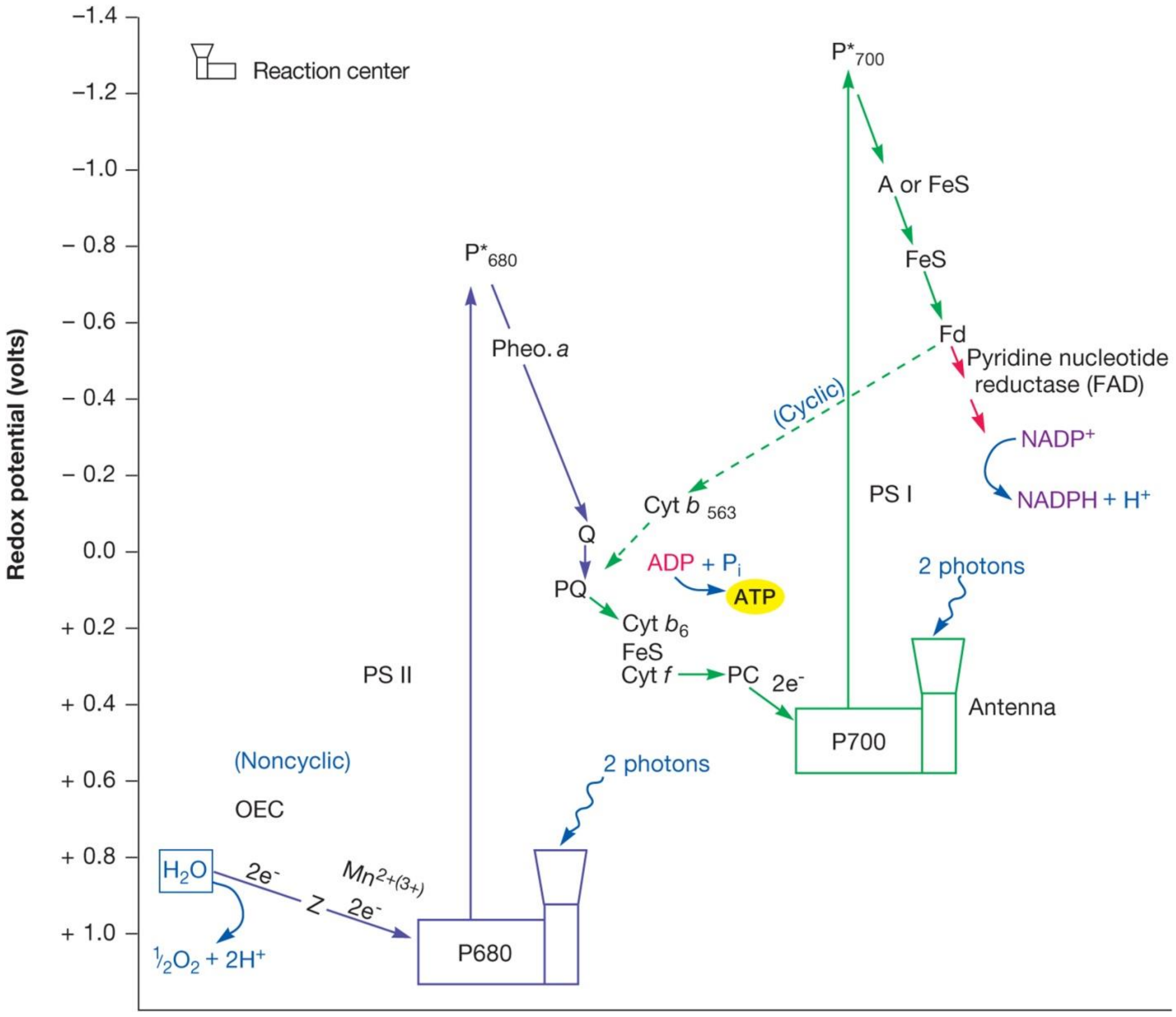
Organization of Pigments

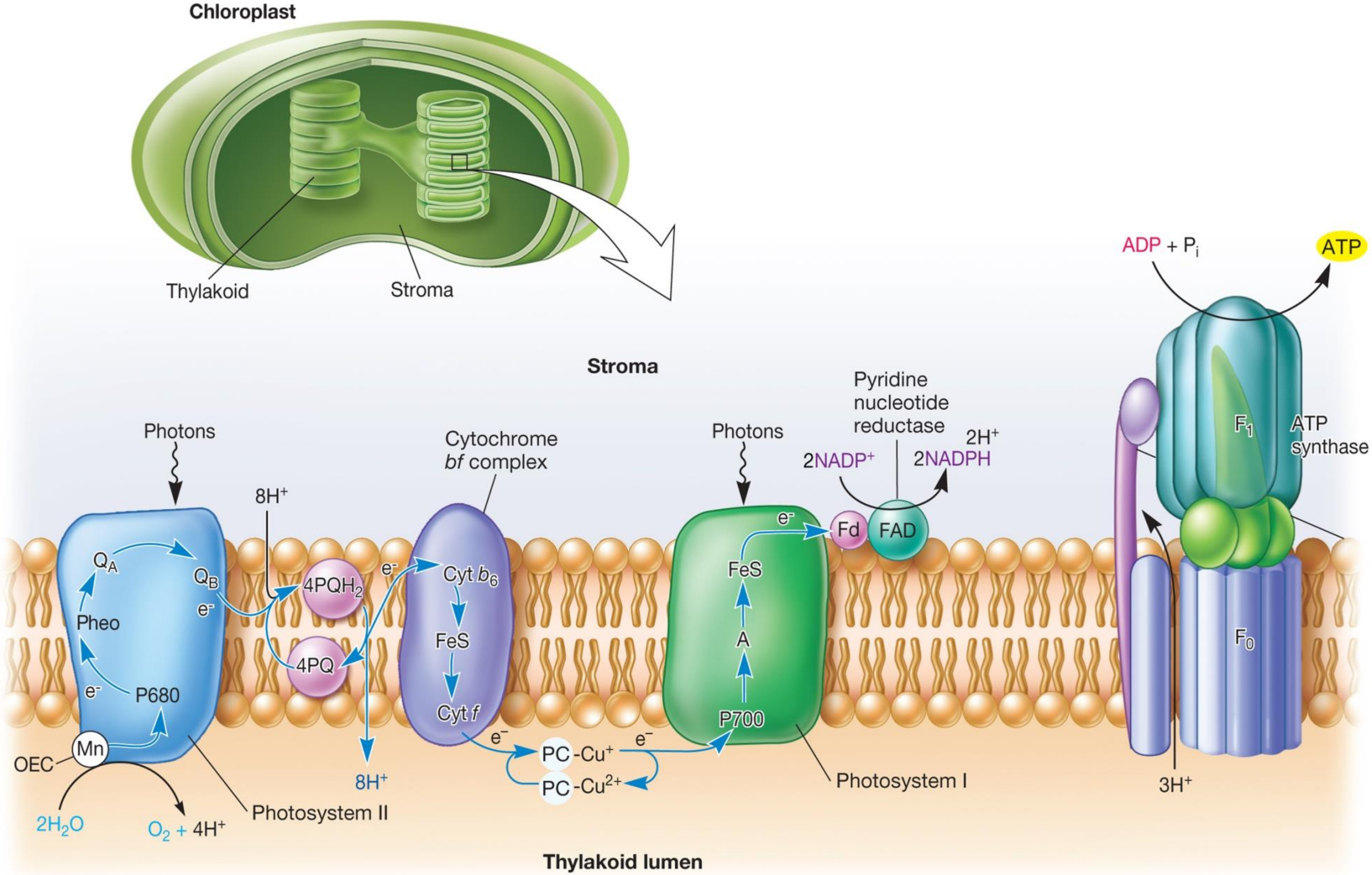
- Antennas
  - highly organized arrays of chlorophylls and accessory pigments
  - captured light transferred to special reaction-center chlorophyll
    - directly involved in photosynthetic electron transport
- Photosystems
  - antenna and its associated reaction-center chlorophyll
- Electron flow $\rightarrow$ PMF $\rightarrow$ ATP

Oxygenic Photosynthesis

Noncyclic electron flow – ATP + NADPH made (noncyclic photophos-phorylation)

Cyclic electron flow – ATP made (cyclic photophos-phorylation)

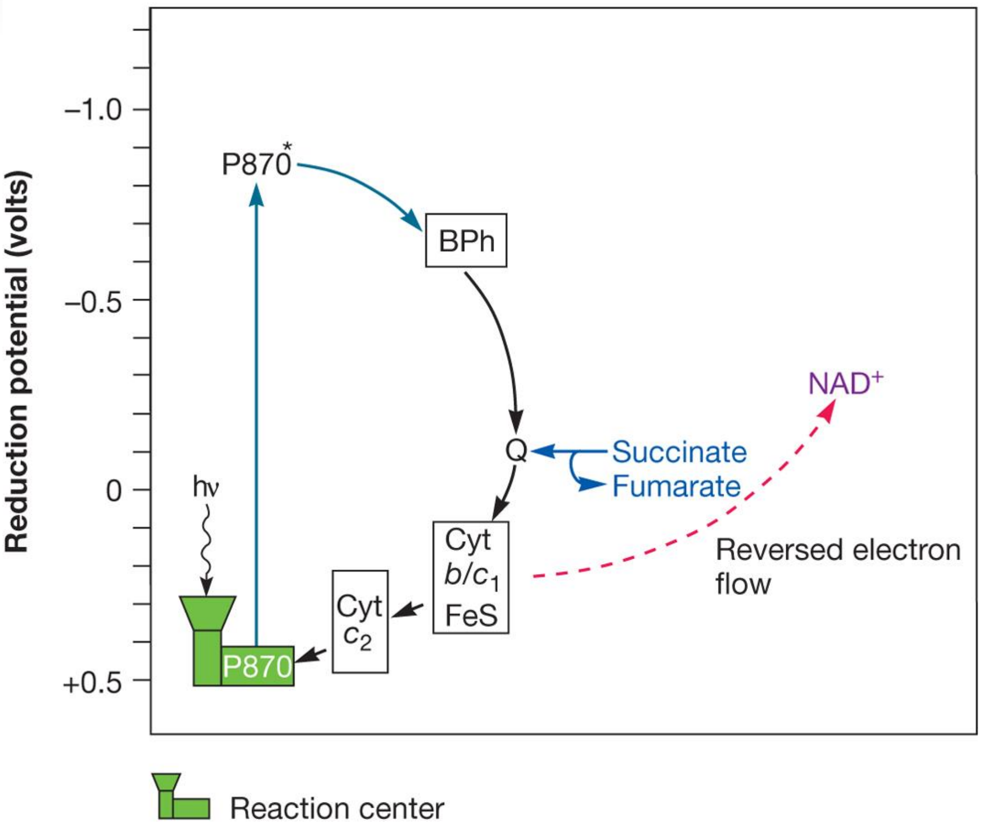




Chloroplast
Thylakoid
Stroma
Stroma
Photons
Photosystem II
Q_A
Q_B
Pheo
P680
e⁻
Mn
OEC
$2H_2O$
$O_2 + 4H^+$
$8H^+$
$4PQH_2$
4PQ
$8H^+$
Cytochrome *bf* complex
Cyt b_6
FeS
Cyt *f*
$PC\text{-}Cu^+$
$PC\text{-}Cu^{2+}$
Photons
FeS
A
P700
Photosystem I
Fd
FAD
Pyridine nucleotide reductase
$2NADP^+$
$2H^+$
2NADPH
ADP + P_i
ATP
F_1
ATP synthase
F_0
$3H^+$
Thylakoid lumen

The Light Reaction in Anoxygenic Photosynthesis

- H_2O not used as an electron source; therefore O_2 is not produced
- Only one photosystem involved
- Uses bacteriochlorophylls and mechanisms to generate reducing power
- Carried out by phototrophic green bacteria, phototrophic purple bacteria, and heliobacteria



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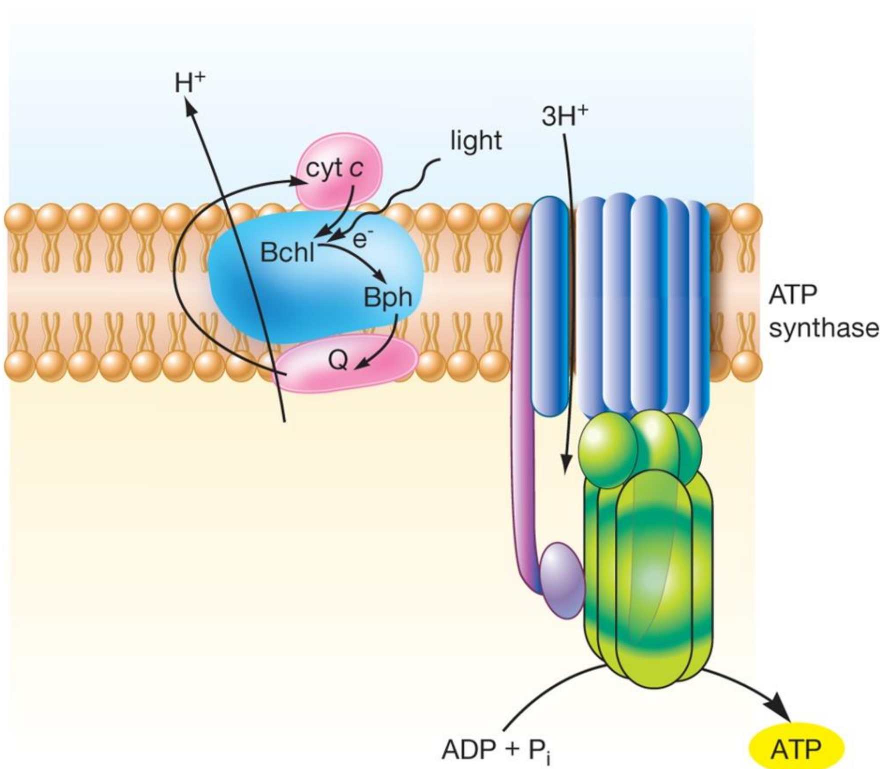

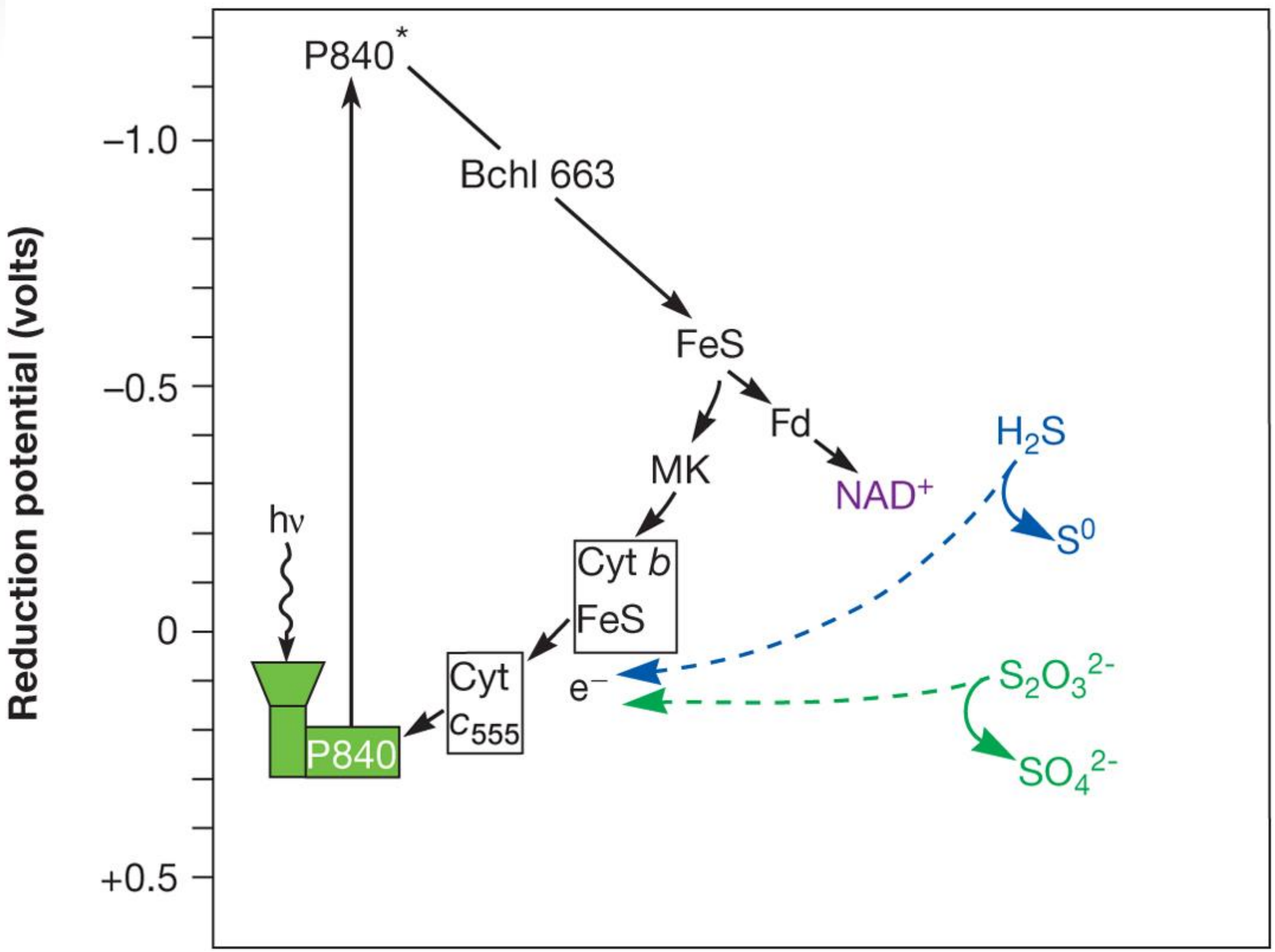
Reduction potential (volts)
−1.0
−0.5
0
+0.5
P840*
Bchl 663
FeS
Fd
MK
NAD+
H2S
S0
hν
Cyt b
FeS
Cyt
c555
e−
S2O3 2-
SO4 2-
P840

Bacteriorhodopsin-Based Phototrophy

- Some archaea use a type of phototrophy that involves bacteriorhodopsin
  - a membrane protein
  - functions as a light-driven proton pump
- A proton motive force is generated
- An electron transport chain is not involved