BIO 311C
Spring 2010

Lecture 28 – Wednesday 7 Apr.

Some Intermediate and Final Products of Respiration

Review

From Glycolysis		2 ATP/glucose
		2 NADH/glucose
		2 pyruvate/glucose
From Pyr Dehydrogenase	1 NADH/pyruvate	2 NADH/glucose
	1 CO_2/pyruvate	2 CO_2/glucose
	1 C_2-CoA/pyruvate	2 C_2-CoA/glucose
From the Krebs Cycle	3 NADH/C_2-CoA	6 NADH/glucose
	1 $FADH_2$/C_2-CoA	2 $FADH_2$/glucose
	1 ATP/C_2-CoA	2 ATP/glucose
	2 CO_2/C_2-CoA	4 CO_2/glucose

Sum - each molecule of glucose metabolized through glycolysis, pyruvate dehydrogenase and the Krebs cycle produces:

6 CO_2 diffuses out of the cell

10 NADH
2 $FADH_2$
} remain in the mitochondrion, where they are further metabolized

4 ATP is distributed throughout the cell

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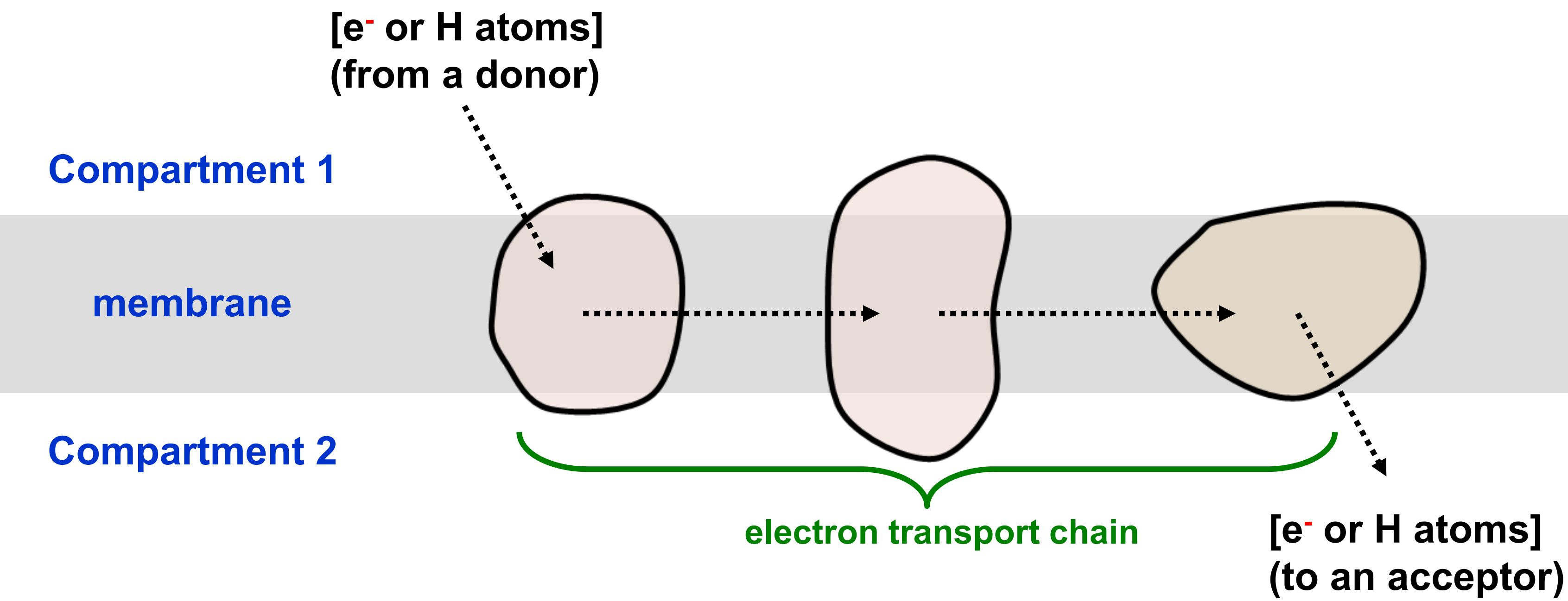
Review

An Electron Transport Chain Within a Biological Membrane



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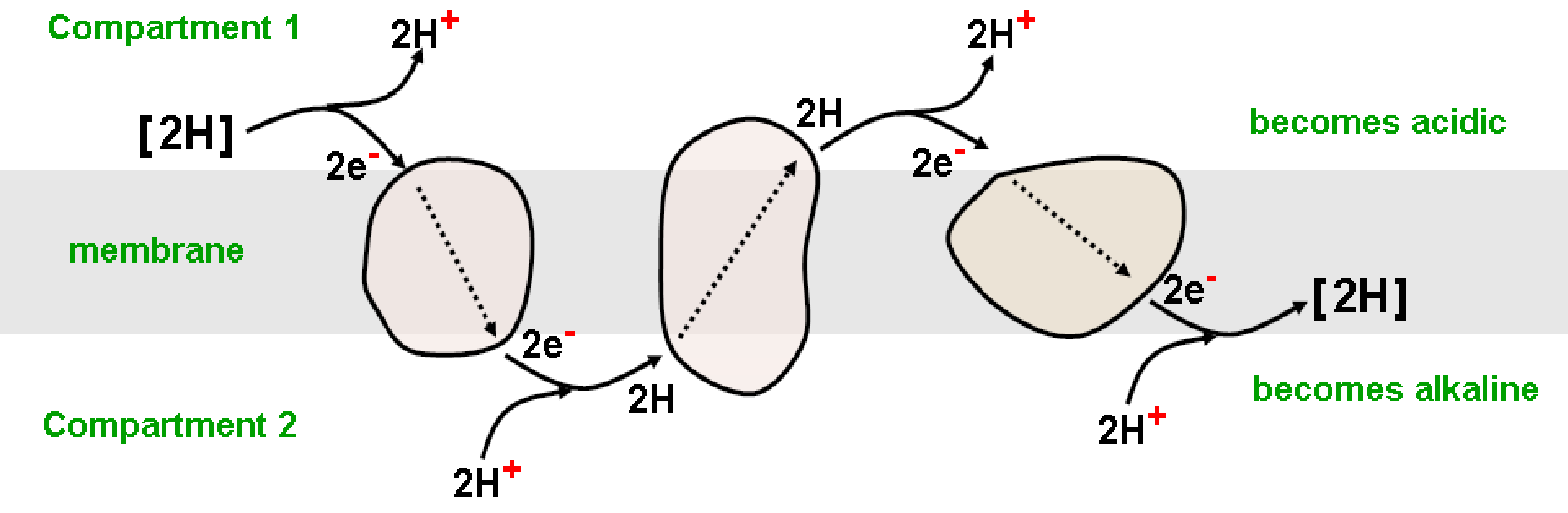
Principle of Operation of an Electron Transport Chain to Generate a Proton Gradient Across a Membrane



The carriers of reducing units alternate between hydrogen-atom carriers and electron carriers. Whenever protons are needed, they are withdrawn from one side of the membrane; whenever protons are produced, they are released to the other side of the membrane. Thus a difference in pH and a difference in electric charge is generated across the membrane.

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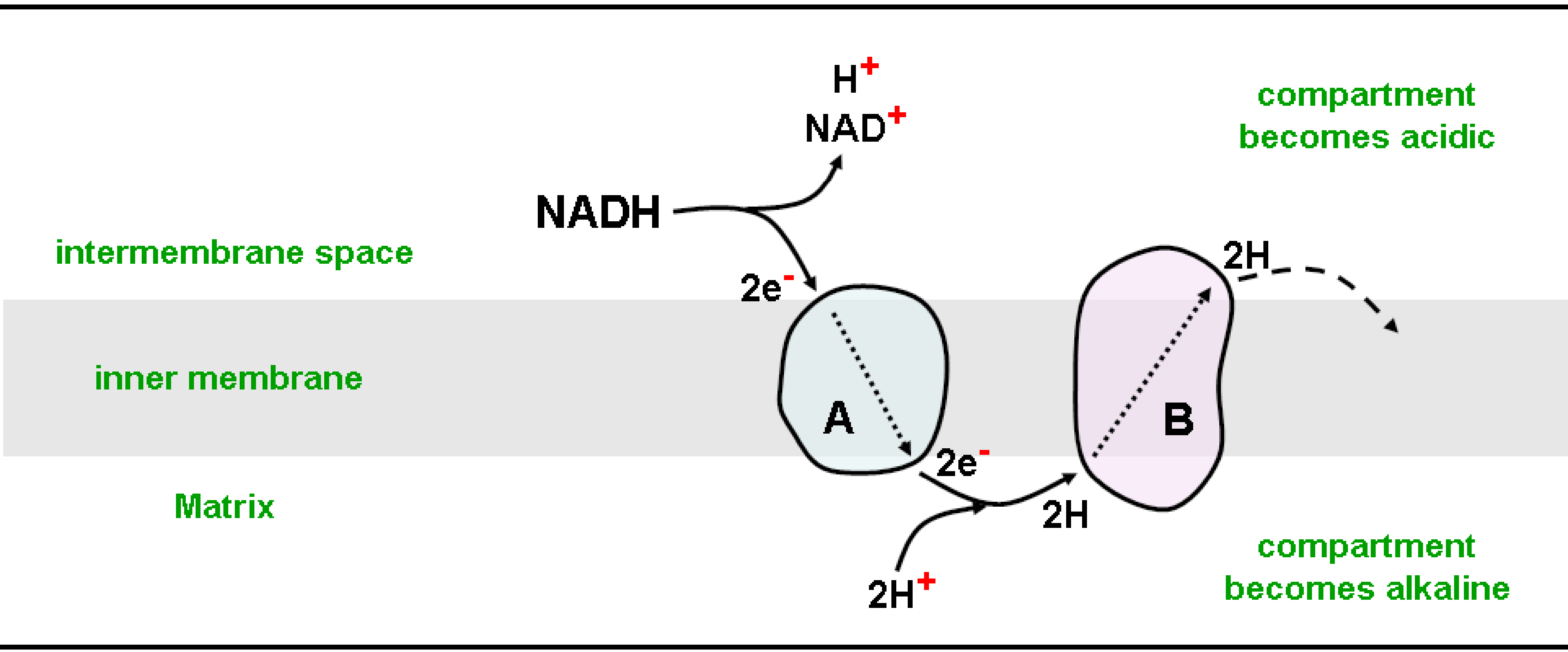
Initial Components of the Electron-transport Chain of the Mitochondrial Inner Membrane



Component A is an electron carrier.
Component B is a hydrogen-atom carrier.

A proton is released into the intermembrane space when the electrons from NADH are transferred to Component A. Protons are withdrawn from the matrix when hydrogen atoms are transferred to Component B.

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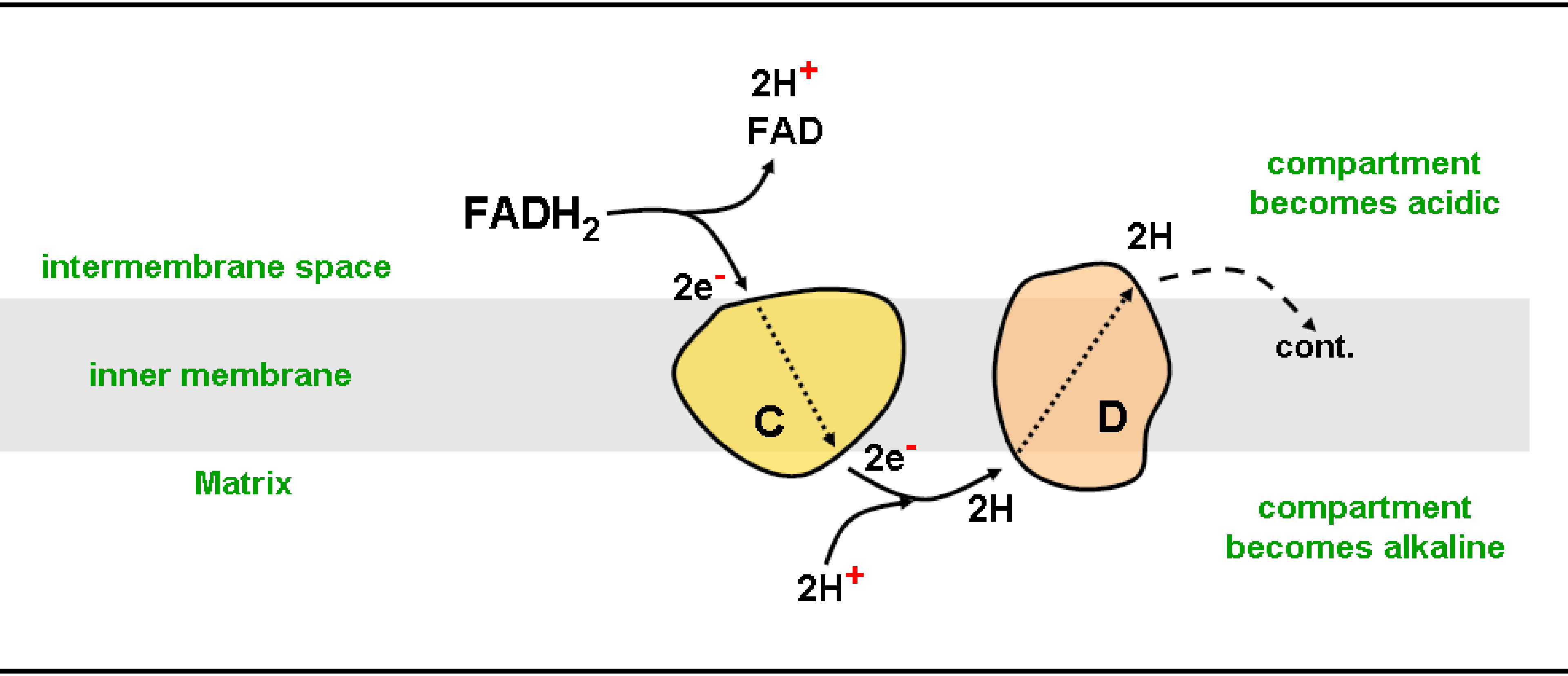
$FADH_2$ also donates electrons to an electron transport chain of the mitochondrial inner membrane.



Reducing units from $FADH_2$ that are used in the electron transport cause the H^+ concentration in intermembrane space to increase and the H^+ concentration in the matrix to decrease.

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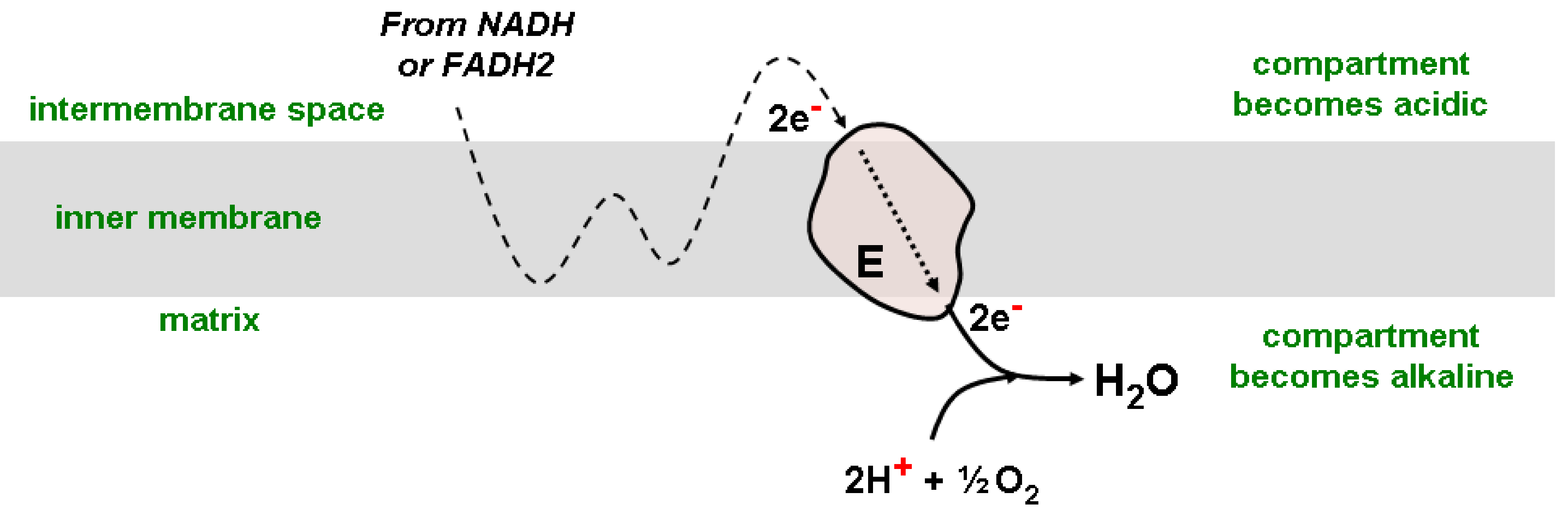
Electrons entering the mitochondrial electron transport chain from either NADH or $FADH_2$ are ultimately transferred to O_2 which, along with protons drawn from the matrix, reduce the O_2 to water.



Protons are removed from the matrix during electron transport to water, making the matrix more alkaline with respect to the intermembrane space.

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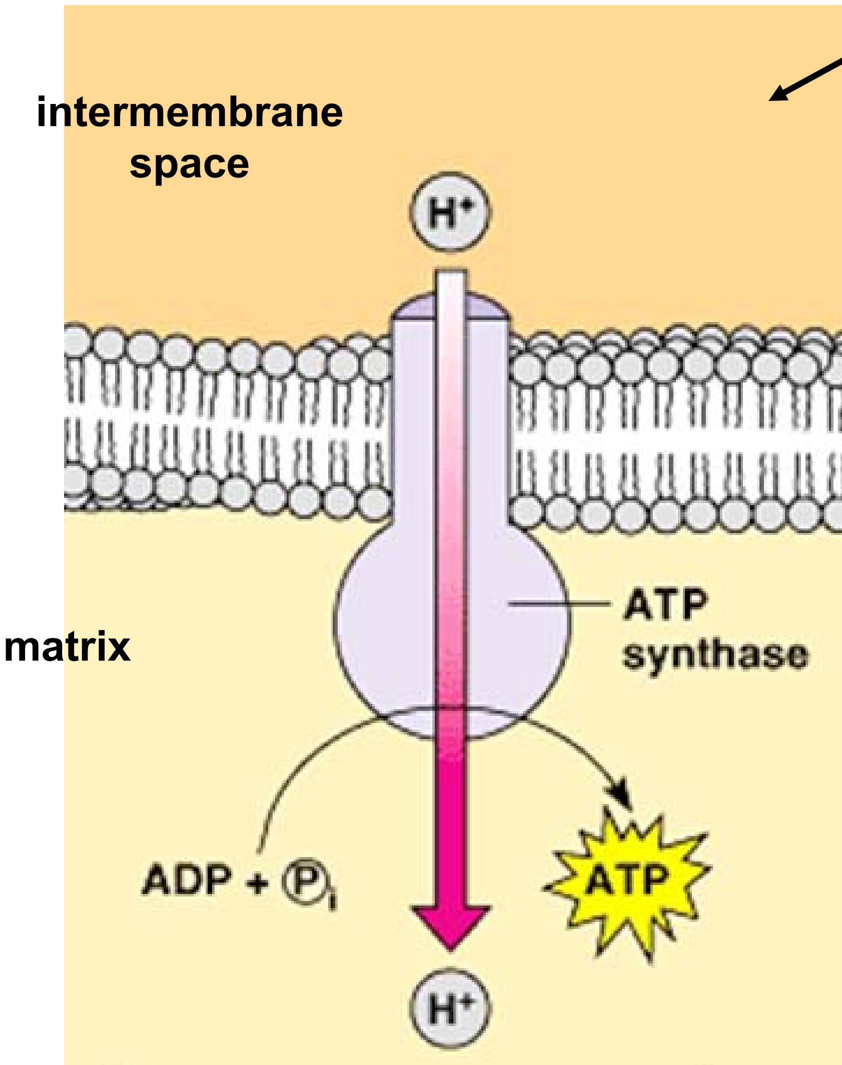
Function of ATP Synthase in the Mitochondrial Inner Membrane



Mitochondrial electron transport causes a higher concentration of H^+ on this side of the membrane.

The resulting difference in pH and electric charge across the membrane is a form of stored energy.

The only path available for protons to travel back across the membrane to neutralize the pH and electric charge on both sides of the membrane is through ATP synthase, an <u>enzyme</u> <u>complex</u> that captures as ATP some of the energy released during proton flow.

An <u>enzyme</u> <u>complex</u> may be defined as a structure composed of several or many polypeptide chains that attach together in order to perform one or more enzymatic reactions. e.g. Pyr dehydrogenase is sometimes called an enzyme complex. Recall that we called Pyr dehydrogenase a metabolic pathway.

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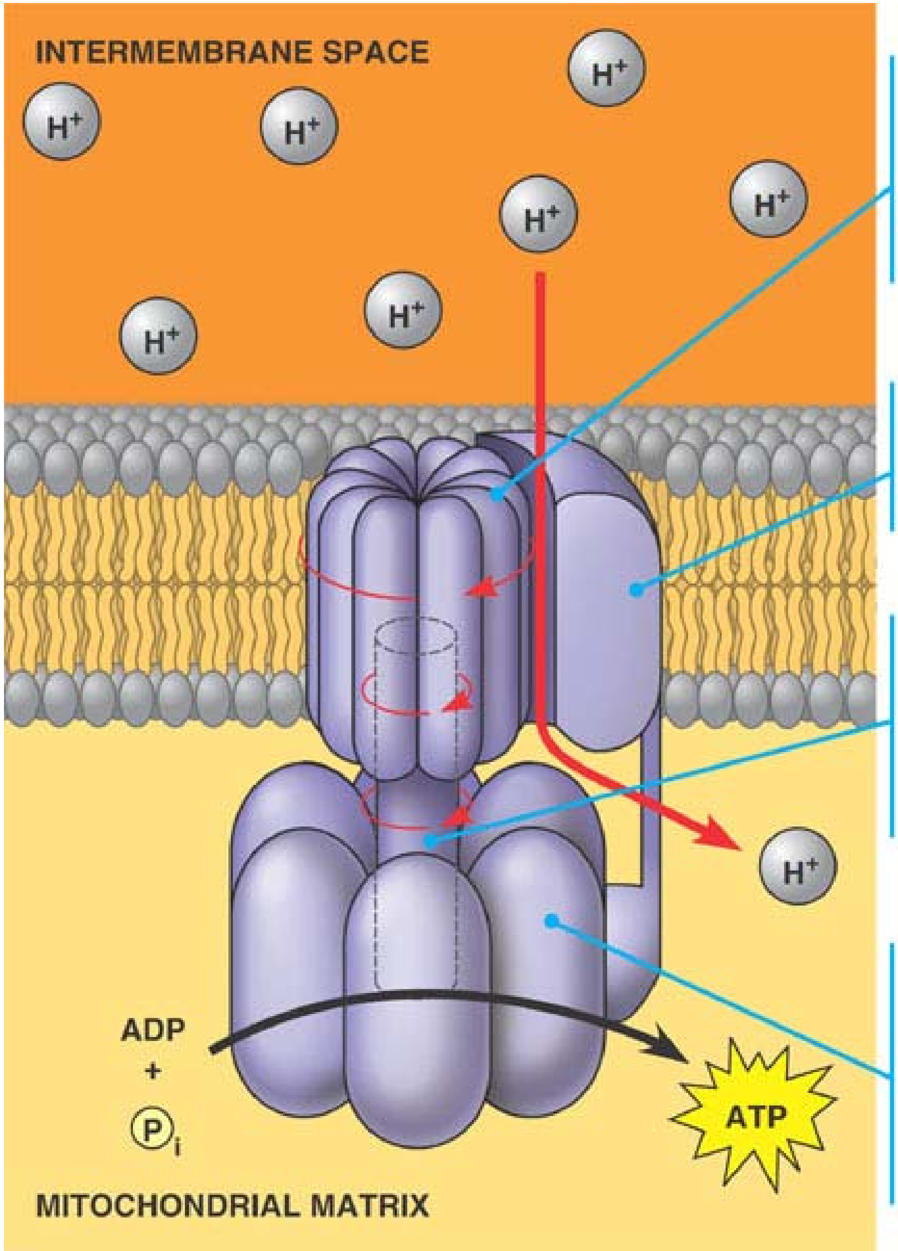
Structure & Functions of ATP Synthase, a transmembrane Enzyme Complex Containing a Transmembrane component and a Peripheral component

From textbook Fig. 9.14, p. 174



A rotor within the membrane spins clockwise when H^+ flows past it down the H^+ gradient.

A stator anchored in the membrane holds the knob stationary.

A rod (or "stalk") extending into the knob also spins, activating catalytic sites in the knob.

Three catalytic sites in the stationary knob join inorganic phosphate to ADP to make ATP.

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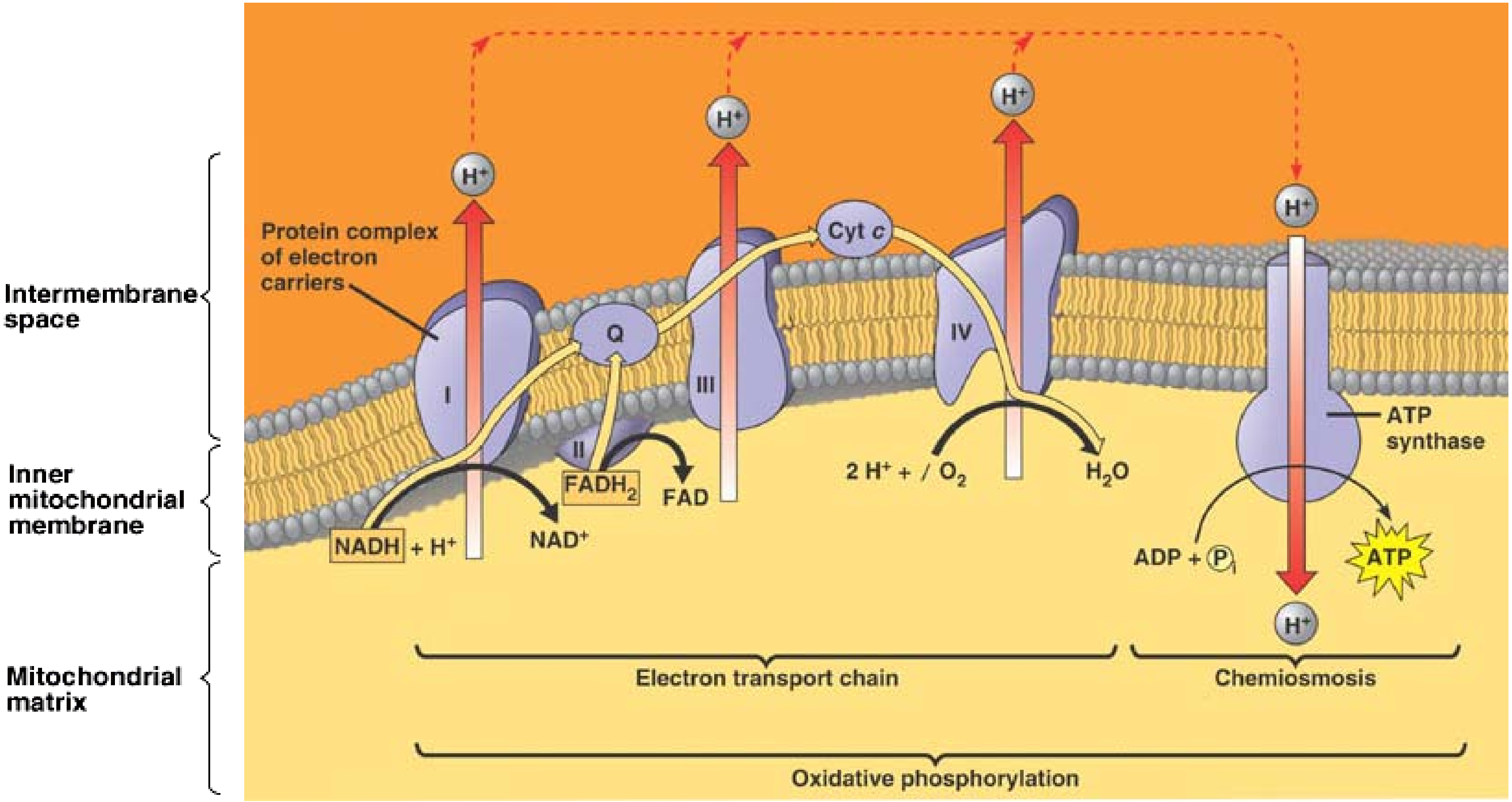
Chemiosmosis is the name of the process that synthesizes ATP from the dissipation of a proton gradient across a biological membrane.

From textbook Fig. 9.16, p. 175



Oxidative phosphoryation is the sum of:

1. the generation of a proton gradient across the mitochondrial inner membrane during electron transport, and
2. the synthesis of ATP during the dissipation of the previously generated proton gradient (chemiosmosis).

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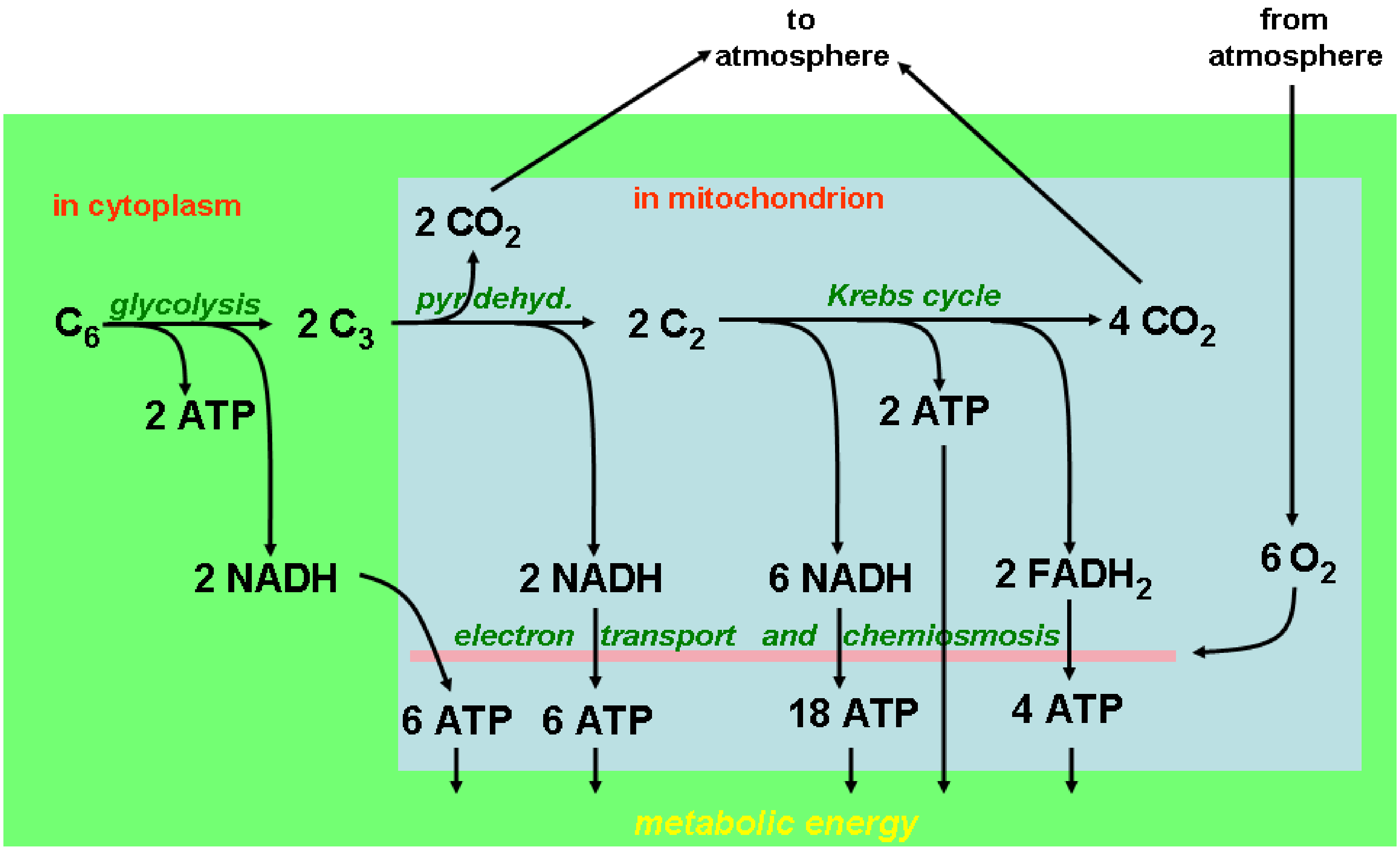
Summary of the Metabolic Pathways and Processes of Respiration



Approximately 38 molecules of ATP are synthesized per glucose molecule respired. However, in eukaryotes 2 ATP per glucose are required to move respiratory substrates pyruvate, NADH, ADP and P_i into the mitochondrion, and substrates NAD^+ and ATP out of the mitochondrion, by active transport. Thus, in eukaryotes there is a net production of 36 ATP per glucose.

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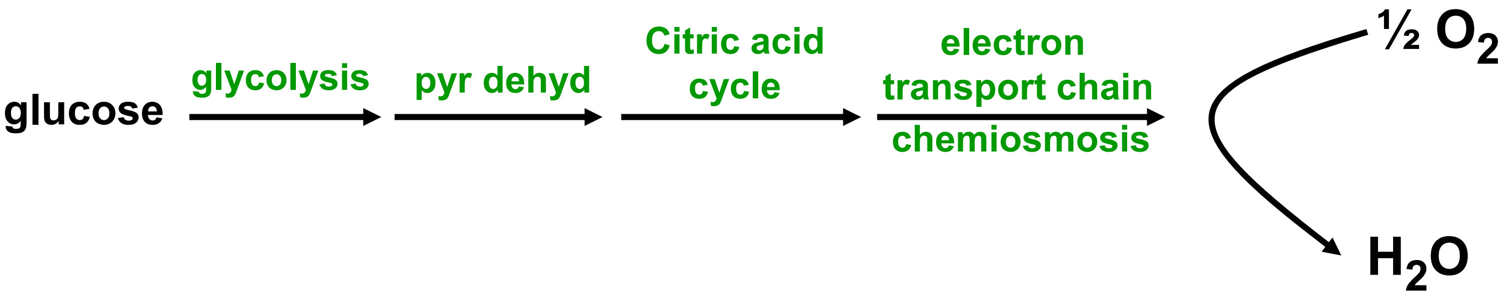
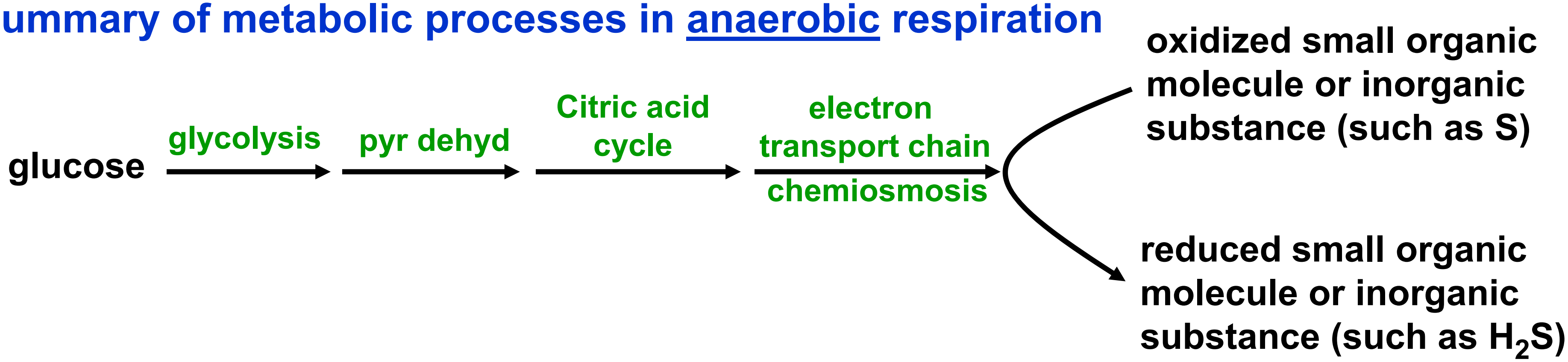
Some kinds of microorganisms are capable of doing respiraton in the absence of O_2. That process is called anaerobic respiration.

summary of metabolic processes in <u>aerobic</u> respiration



summary of metabolic processes in <u>anaerobic</u> respiration



Aerobic and anaerobic respiration are identical except that in anaerobic respiration a substance other than O_2 serves as the final (terminal) accepter of reducing units in the electron transport chain.

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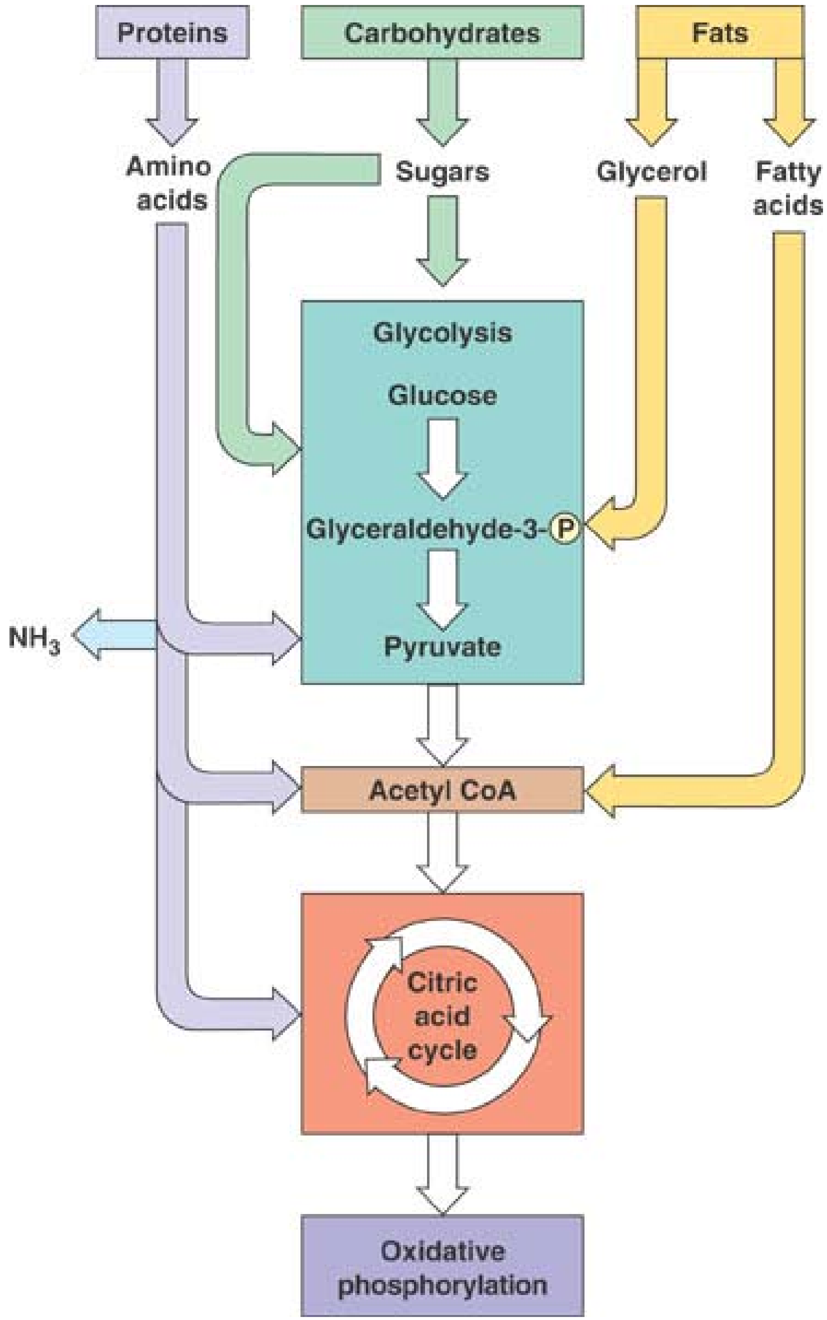
Catabolism of various fuel molecules



These substances serve as <u>fuel</u> (energy-supplying) molecules rather than as <u>food</u> (construction) molecules when they are used in respiration.

Textbook Fig. 9.20, p. 180

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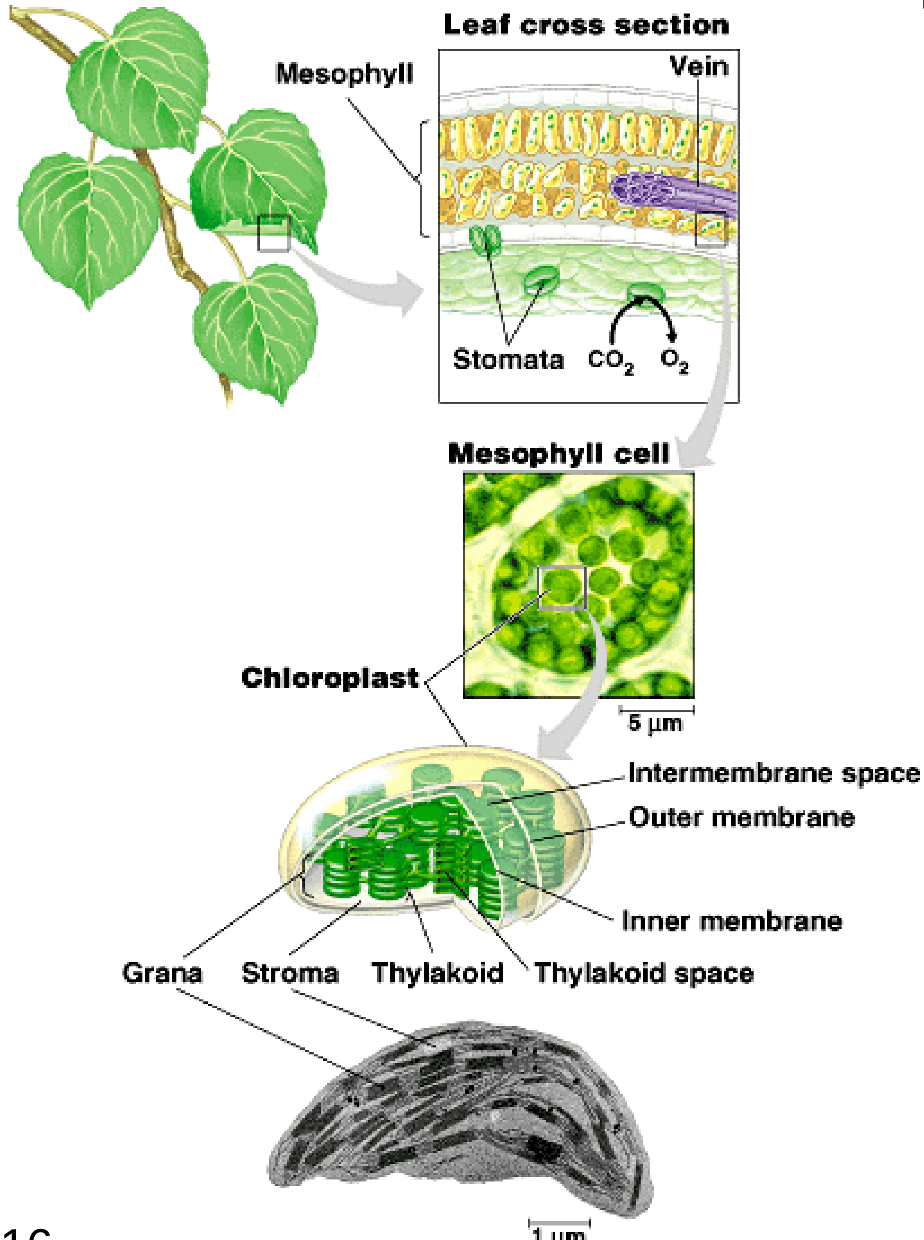
The location of photosynthesis in a plant



From textbook Fig. 10.3, p. 187

The interior spaces of leaves are mostly sealed from the external environment, but the under-surface of leaves contain pores that allow the entrance of CO_2 and the exit of O_2 needed for photosynthesis, and to allow the evaporative loss of water vapor.

Photosynthesis occurs in chloroplasts. Since chloroplasts typically are green, the tissues that do photosynthesis are generally green in color.

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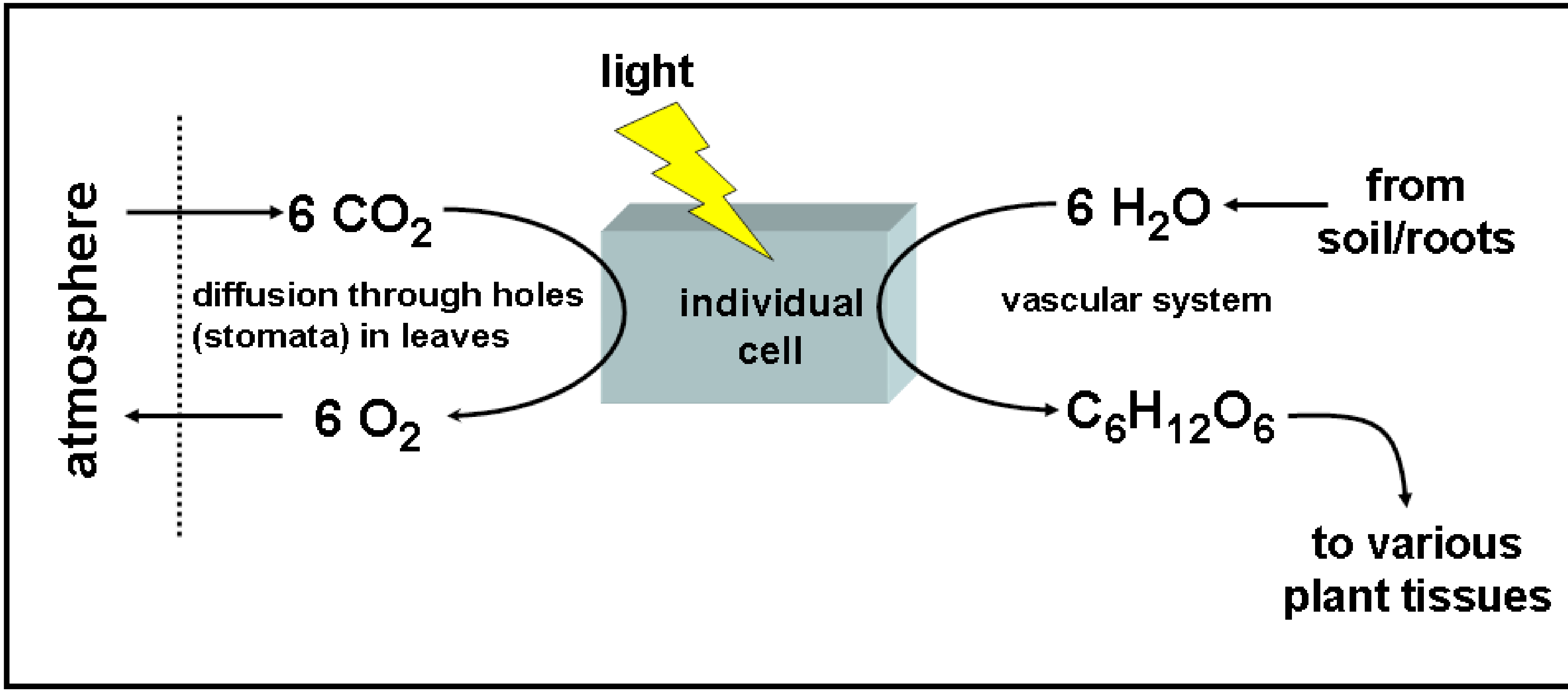
Photosynthesis in plants (from a physiological perspective)



net reaction

$$6\ CO_2 + 6\ H_2O \xrightarrow[\text{photosynthesis}]{\text{light energy}} C_6H_{12}O_6 + 6\ O_2$$

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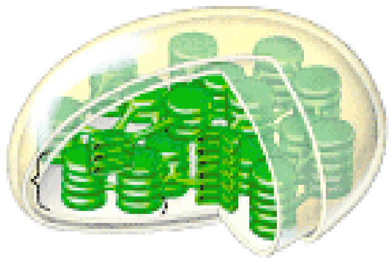
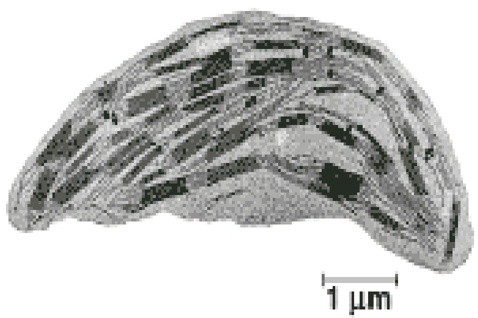
Chloroplast Structure





From textbook Fig. 10.3, p. 187

Chloroplasts are a kind of large plastid found in green plant cells, often 5 µm or larger in diameter.

The chloroplast envelope consists of two membranes (an outer membrane and an inner membrane) along with an intermembrane space.

Internal to the envelope is a watery space called the stroma, within which is imbedded an interconnected system of membranes called thylakoids.

Thylakoids enclose internal spaces called the lumen.

Thus, the chloroplast contains three different membrane systems (the outer membrane and inner membrane of the envelope, and thylakoid membranes), which separate three distinct aqueous spaces (the intermembrane space, the stroma and the lumen) from the cytoplasmic matrix. The reactions of photosynthesis require the stroma and the lumen, as well as the thylakoid membrane that separates these spaces.

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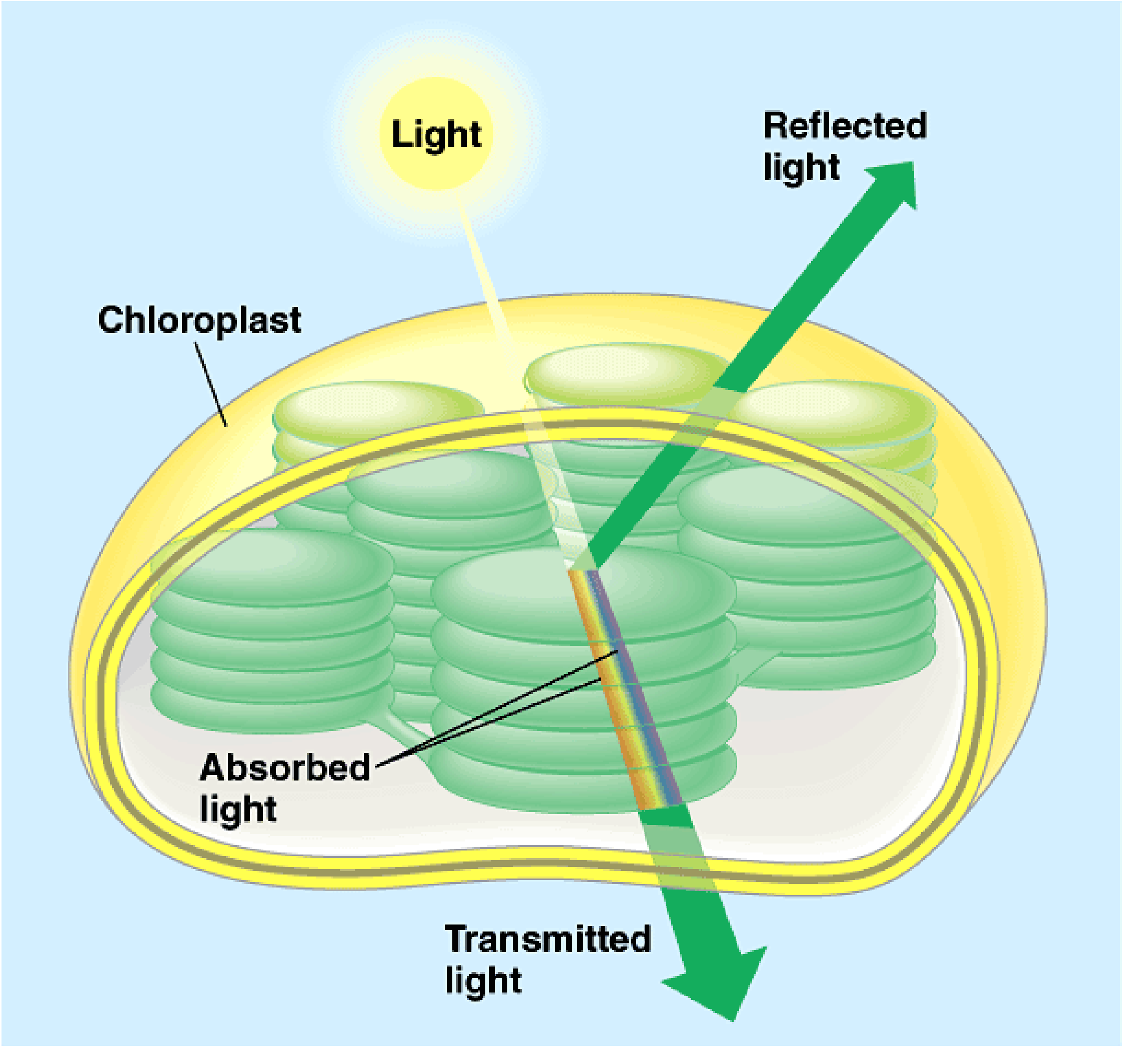
Why leaves are green

From textbook Fig. 10.7, p. 190



Light from the sun contains a mixture of all colors. Colored molecules (pigments) in the chloroplasts absorb all colors except green quite efficiently. Thus, mostly green light passes on through the chloroplast or is reflected from it.

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The overall chemical equation for photosynthesis is very similar to the reverse of the chemical equation for respiration.

$$6\ CO_2 + 6\ H_2O \xrightarrow[\text{photosynthesis}]{\text{light energy}} C_6H_{12}O_6 + 6\ O_2$$

$$C_6H_{12}O_6 + 6\ O_2 \xrightarrow[\text{ATP}]{\text{respiration}} 6\ CO_2 + 6\ H_2O$$

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A metabolic pathway or process must be exergonic (spontaneous) in order to go in the forward direction, regardless of whether it is anabolic or catabolic.

$\Delta G < 0$

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Both photosynthesis and respiration are exergonic processes.

light energy

$$6\ CO_2 + 6\ H_2O \xrightarrow{\text{photosynthesis}} C_6H_{12}O_6 + 6\ O_2 \qquad \Delta G^o \approx -9{,}000\ \text{kJ/mole}$$

heat

$$C_6H_{12}O_6 + 6\ O_2 \xrightarrow{\text{respiration}} 6\ CO_2 + 6\ H_2O \qquad \Delta G^o \approx -1{,}700\ \text{kJ/mole}$$

ATP heat

Photosynthesis is an anabolic process.
Respiration is a catabolic process.

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Carbon flow in Photosynthesis

6 of C_1 ⟶ 1 of C_6

Carbon flow in Respiration

1 of C_6 ⟶ 6 of C_1

The C_6 of both photosynthesis and respiration is hexose (typically glucose).

The C_1 of both photosynthesis and respiration is CO_2.

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Summary of Energy flow in photosynthesis

light energy

energy input ≈ 12,000 kJ/(mole of C_6)

$$6\ CO_2 + 6\ H_2O \longrightarrow C_6H_{12}O_6 + 6\ O_2$$

heat

Energy required = $\Delta G°$
≈ +2,880 kJ/(mole of C_6)

$$\text{efficiency} \approx \frac{2{,}880\ \text{kJ/mole}}{12{,}000\ \text{kJ/mole}} \times 100\ \% \approx 24\ \%$$

The remaining 76% of the energy introduced by light is given off as heat, assuring that photosynthesis is an exergonic process.

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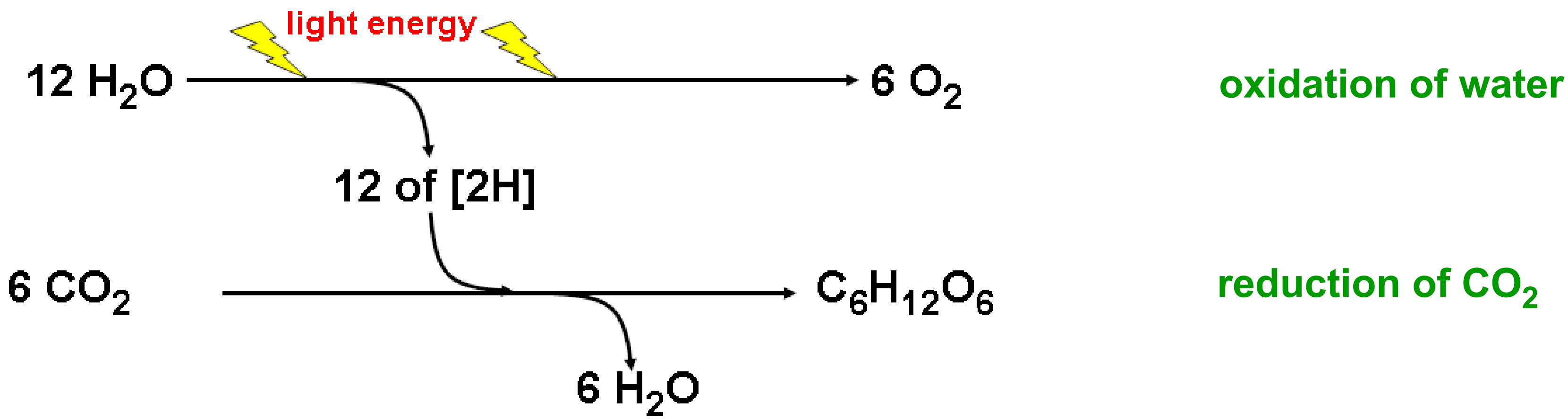
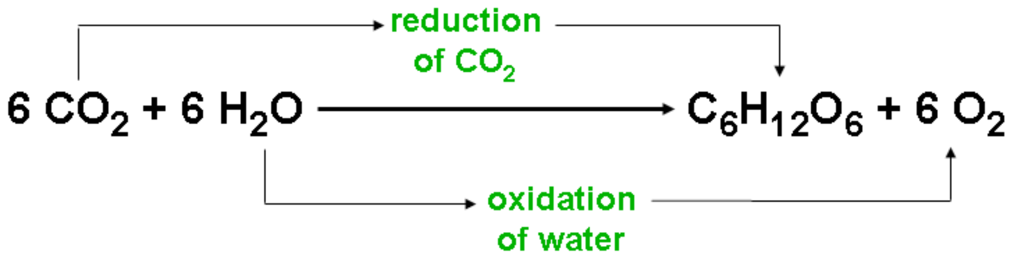
Overview of Oxidation and Reduction in Photosynthesis





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Metabolic Pathways and Processes that Participate in Photosynthesis

- Light harvesting and energy trapping
- Photosynthetic electron transport
- Chemiosmosis

light reactions of photosynthesis

- Calvin Cycle

dark reactions of photosynthesis

Photophosphorylation

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