

Biochemistry—Photosynthesis and Respiration

A. Photosynthesis background

1. Why do we consider O_2 a booster of evolution?

The organisms doing only glycolysis were slow and small. The net gain of 2ATP molecules from a molecule of glucose is not enough to fuel more complicated organisms that populate the biosphere today. For that, photosynthesis and respiration needed to develop. The waste product of non-cyclic photosynthesis is O_2 , and its presence allowed respiration to develop, since O_2 could be used as an electron acceptor.

2. Why was it advantageous for a cell to develop photosynthesis?

When abiotic sources of energy started to decline, it became advantageous to have the ability to make ATP. While glycolysis allows an organism to make ATP, it requires a source of organic carbon. Developing photosynthesis allowed an organism to become an autotroph—make everything it needs from CO_2 , NH_3 , PO_4 , H_2O . Thus, in the environment low in abiotic sources of energy and carbohydrates photosynthetic organisms have selective advantage.

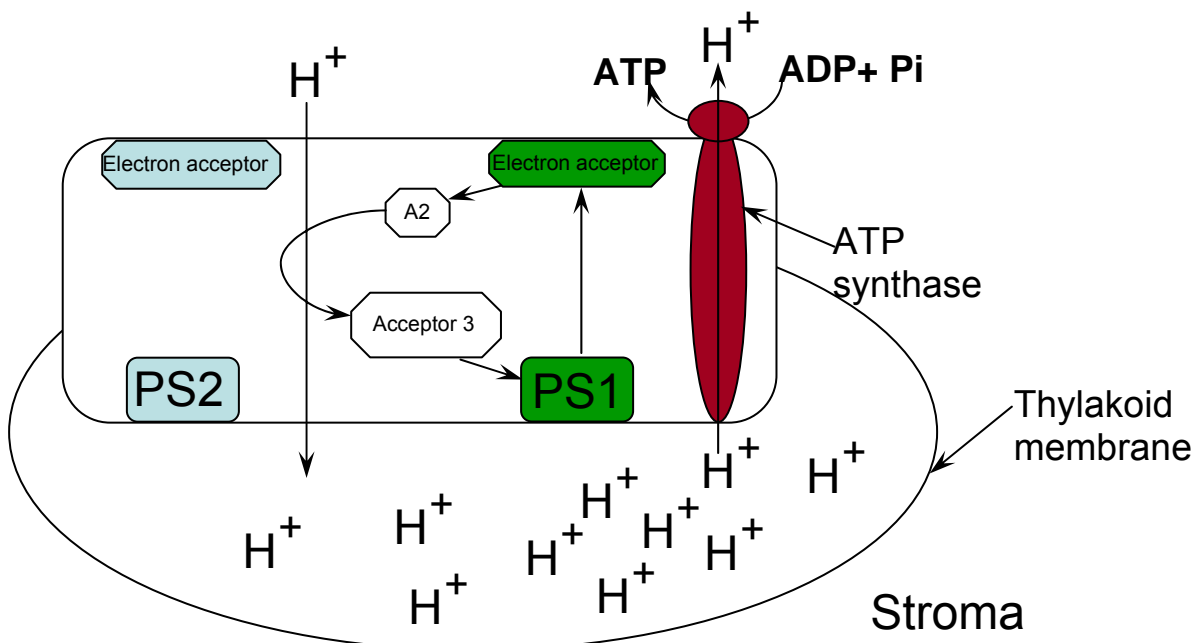
3. Photosynthesis has two phases—light and dark. What does each phase accomplish?

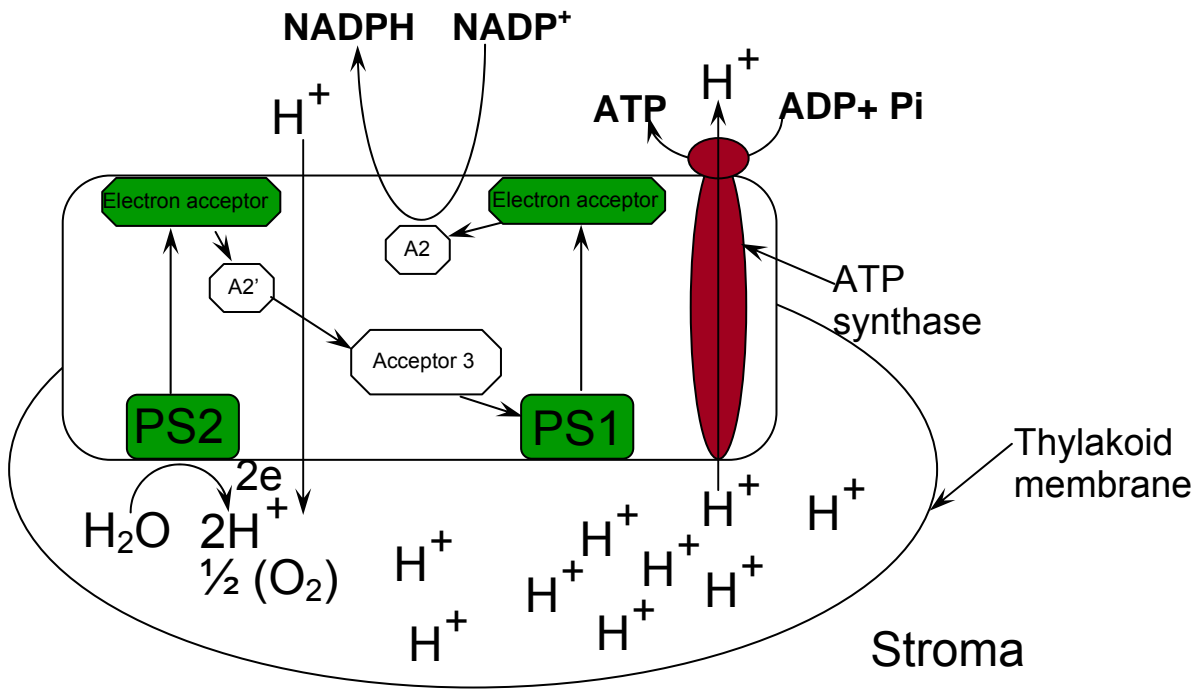
The light phase is so named because it is dependent on the presence of light to drive its reactions. Light phase reactions use the energy of the excited chlorophylls to make ATP and NADPH, while producing O_2 as a waste product.

The dark phase is so named because it is independent from the presence of light. Dark phase is also known as a biosynthetic phase—the phase in which atmospheric CO_2 is fixed into organic carbon.

B. Photosynthesis—light reactions

1. Below are the schematics for cyclic and noncyclic photophosphorylation. Identify each schematic and discuss the order of steps in each process.





First schematic is of cyclic photophosphorylation. Steps:

- 1) The process starts when a photon hits a PS1(photosystem 1) chloroplast, exciting two electrons on the molecule.
- 2) The two electrons are donated to the electron acceptor (creating a “hole” in the molecule), then
- 3) Passed to Acceptor 2(A2), and on to Acceptor 3 [both of these have names, but you do not need to remember them]. The later step powers the active transport of hydrogen ions from stroma into the thylakoid space.
- 4) Electrons pass from Acceptor 3 back to the PS1 chloroplast (thus, filling the “hole” in the molecule left by the electrons in step 2)).
- 5) H^+ gradient drives the ions through the ATP synthase, powering the addition of a P_i to an ADP, creating ATP.

Second schematic is of noncyclic photophosphorylation. Steps:

- 1) The process starts when a photon hits a PS2(photosystem 2) chloroplast, exciting two electrons on the molecule.
- 2) The two electrons are donated to the electron acceptor (creating a “hole” in the molecule).
- 3) Water is split in the thylakoid, providing the electrons to fill the “hole” in the PS2 molecule. O_2 is released as waste product. $2H^+$ ions are created, to be used in step 7 below.
- 4) Electrons from the acceptor are passed to A2', and on to Acceptor 3 [again, all of these have names, but you do not need to remember them]. The later step powers the active transport of hydrogen ions from stroma into the thylakoid space.
- 5) Electrons pass from Acceptor 3 to the PS1 chloroplast that was hit by a separate photon, exciting it, and creating a “hole.”
- 6) Electrons from the PS1 chloroplast are passed on to the electron acceptor and on to A2.
- 7) Electrons on A2 and the protons generated in step 3 are used to reduce $NADP^+$ to $NADPH+H^+$.
- 8) H^+ gradient drives the ions through the ATP synthase, powering the addition of a P_i to an ADP, creating ATP.

2. What are the main differences between the two processes?

In cyclic photophosphorylation, electrons come back to chloroplast molecules, while in noncyclic photophosphorylation, the splitting of water provides the electrons to “compensate” the original chloroplast, and produces O₂ as waste product. In addition, noncyclic photophosphorylation produces NADPH as well as ATP. Cyclic photophosphorylation only produces ATP.

3. What is the ATP made in photosynthesis used for?

It is mostly used in dark reactions of photosynthesis to fix CO₂ into glucose.

4. In class we learned that cyclic photophosphorylation produces S as waste product. Yet we do not see S created anywhere in the schematic above. Where and how is S released?

In order to fix CO₂ into organic carbon, a lot of reducing power is needed. This power is provided by NADPH. In cyclic photophosphorylation as we described it so far no NADPH is produced. Another, side reaction is run to produce NADPH from NADP⁺. In that reaction, H₂S serves as an electron donor, and S is released as waste product.

5. Why do cells need to make glucose out of ATP? Why not just use the ATP produced in photosynthesis?

-Hard to store ATP (for long term storage, want currency in gold, not \$)

-Need glucose for other pathways.

Intricate web of pathways—allows a non-photosynthetic cell (a heterotroph) to live on sugar source alone, or a photosynthetic cell (an autotroph) to build everything it needs from a small number of precursors. Many reactions along the way are endergonic—use ATP to power them.

Figure removed due to copyright reasons.

Please see:

http://www.biologie.uni-hamburg.de/b-online/e19_1/metabol.htm

C. Aerobic Respiration – Oxidative Phosphorylation

Dark reactions of photosynthesis are expensive, and glycolysis only produces 2 molecules of ATP. This is very inefficient.

1. What process developed to derive energy from glucose more efficiently? Why was it not possible to develop this process before noncyclic photophosphorylation arose?

Oxidative phosphorylation, or respiratory chain, or electron transport chain. The process requires O₂ as the final electron acceptor, so it could not have arisen before the advent of noncyclic photophosphorylation.

2. Why was it evolutionarily advantageous for a cell to develop aerobic respiration?

An organism that can utilize its energy reserves more efficiently does not need to make or import from the environment as much glucose as a less efficient organism. Thus, in the environment with limited abiotic sources of glucose or sunlight, an organism that can perform respiration would have selective advantage.

Below is a schematic of the mitochondrial membrane and surrounding compartments.

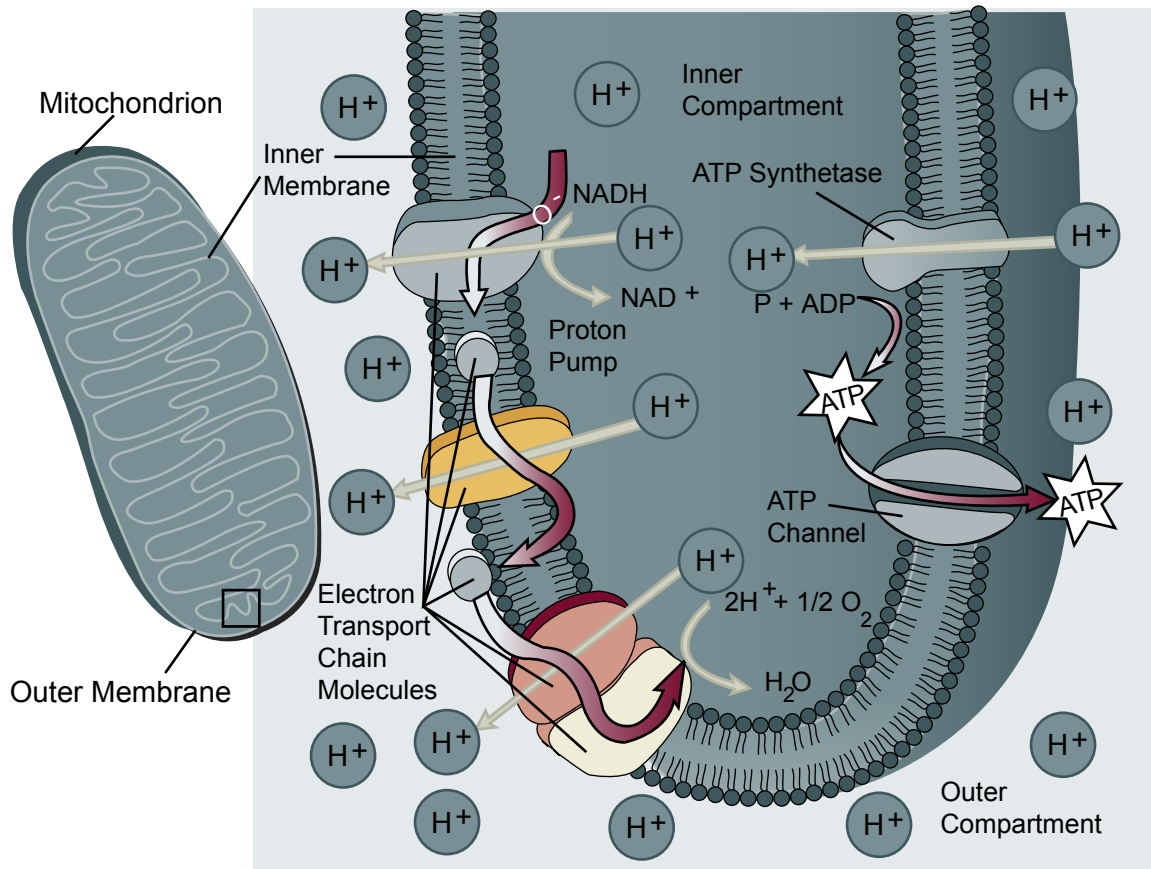


Figure by MIT OCW.

3. Using the schematic, explain why an NADH is “worth” 3 ATPs.

When an NADH molecule donates an electron. That electron is passed through an electron transport chain. Three membrane proteins that take part in the chain are powered by this electron to transport a proton from the inner mitochondrial compartment to the outer mitochondrial compartment. Finally, the electron is accepted by O_2 , generating water. The protons that were transported to the outer compartment now have a large gradient—it is energetically favorable for these protons to get back into the inner compartment. However, the only way they can do so is by passing through the ATP synthase, which uses their chemiosmotic energy to power the addition of a phosphate to an ADP molecule, creating ATP. Because each NADH molecule accounts for three protons pumped into the outer compartment, it helps generate three new ATP molecules. Thus, 1 NADH is worth 3 ATPs.

On the way to complete oxidation, each pyruvate molecule generates 4 NADH molecules, one $FADH_2$ molecule, and one ATP molecule. $FADH_2$ can participate in the proton gradient mechanism as well, but only generates 2 molecules of ATP for each molecule of $FADH_2$.

4. In lecture it was said that 36 molecules of ATP total are derived from a glucose molecule via glycolysis followed by aerobic respiration. Describe where these ATP molecules come from.
Glycolysis generates 2 molecules of ATP, 2 molecules of NADH, and 2 molecules of pyruvate. Each molecule of pyruvate is worth 15 ATPs ($4NADH \rightarrow 12ATPs$; $FADH_2 \rightarrow 2ATPs$, and one ATP molecule generated along the oxidation route). Taking into account the two ATPs from glycolysis, that makes 32ATPs. Taking into account the 2 NADHs from glycolysis, we should be looking at 38 ATPs. However, two ATPs are spent moving the electrons from these NADHs produced in the cytoplasm into the mitochondria, where ETC can take place. So overall count is 36 ATPs from each molecule of glucose.