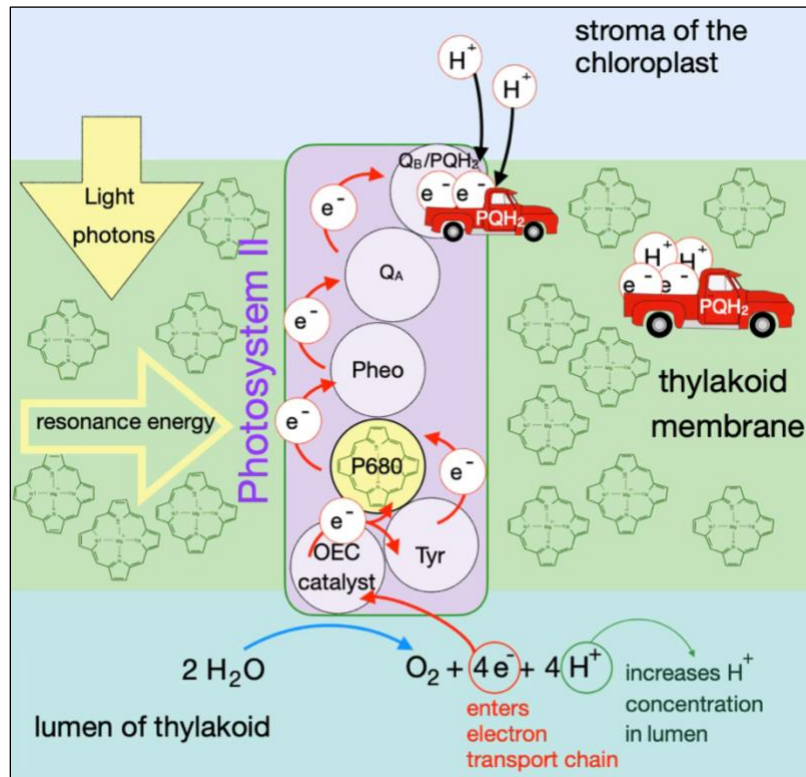


Photosystem II



OEC: oxygen evolving catalyst

Tyr: tyrosine site of a protein

P680: reactive pair of chlorophyll

Pheo: pheophytin

Q_A: plastoquinone A

Q_B: plastoquinone B

PQH₂:
plastohydroquinone

Photosystem II is actually the first photosystem used in photosynthesis. It's called "II" because it was the second photosystem to be discovered by researchers.

The special pair of chlorophyll molecules in Photosystem II¹ are named 'P680.' They are named P680 because the peak of their light absorption curve is that of wavelength 680 nm. They can absorb light directly as well as take in resonance energy from the light harvesting complex. The proteins attached to them hold them very close together, so close that they act as one unit. This allows their electrons to go up much higher in energy – to the point of one electron being released- and picked up by a nearby pheophytin molecule. So, while the chlorophyll in the light harvesting complex transfers energy, the P680 chlorophyll transfers an electron.

As said before, P680 can either directly take in a photon itself, or it can take in resonance energy from the light harvesting complex (LHC). The LHC can take in the energy of a wide range of wavelengths and combine those energies to meet P680's ionization energy. This is a good strategy in low light conditions. The LHC can also protect the plant from too much

¹ The first reaction centre is called Photosystem II (PSII or P680). It was the second reaction centre to be discovered and that is why it is called Photosystem II. It contains a Mn₄CaO₅-cluster that acts as a catalyst in the splitting of the water.

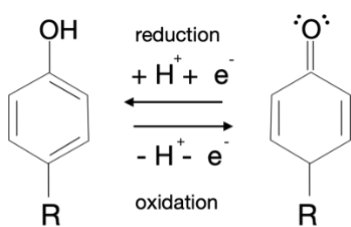
The Light Dependent Stage of Photosynthesis Part II: Photosystem II

light energy (e.g. the intense sunlight at high noon) by dissipating unneeded light energy as heat.

When P680 loses an electron, it becomes P680⁺. P680⁺ has such a high affinity for an electron that it can oxidize water (pull a replacement electron from a water molecule). This causes the water molecule to split apart. But P680⁺ won't take this electron directly because the energy release would be too great if done in a single step. Instead, it will do this in controlled steps in conjunction with a conveniently located tyrosine site of a nearby protein molecule and a powerful four-step catalyst (called the Oxygen-Evolving Complex (OEC)).

The transfer of electrons from water to P680⁺ happens this way:

1. The P680⁺ pulls an electron from (oxidizes) a tyrosine site of a nearby protein.

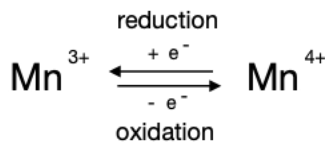


Tyrosine loses both the electron and an H⁺ from its alcohol site (C-OH) to form a ketone (C=O).

This step is irreversible because P680⁺ has a higher reduction potential (greater ability to pull and hold an electron) than tyrosine.

active site of a tyrosine residue

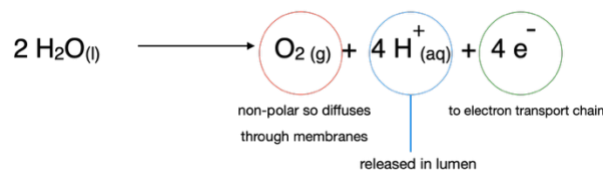
2. The oxidized tyrosine will then pull a replacement electron for itself from an Mn (manganese) ion in the catalyst (the oxygen-evolving complex (OEC)). This further oxidizes the Mn ion.



This step is irreversible because the oxidized tyrosine has a greater reduction potential (greater ability to pull and hold an electron) than the manganese ion.

The manganese catalyst (OEC) contains four manganese ions in a metal cluster (a Mn₄CaO₅ cluster). The Mn ions are oxidized (lose an e⁻) in stages. This builds up the positive charge on the catalyst (OEC) in a slow and controlled way.

3. The metal cluster catalyst is held in place by several proteins. These proteins bind to the lumen side (the inside fluid) of the thylakoid membrane. When the Mn cluster is fully oxidized, it can then pull an electron from a water molecule in the lumen. The loss of this electron causes the water molecule to split into oxygen gas, free electrons and protons.



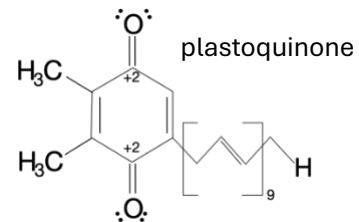
The Light Dependent Stage of Photosynthesis Part II: Photosystem II

Because O_2 is a non-polar molecule, it easily diffuses out through the thylakoid membrane, the chloroplast membrane, the cell membrane, etc. until it passes out of the plant and into our atmosphere. Photosynthesis produces most of earth's oxygen.

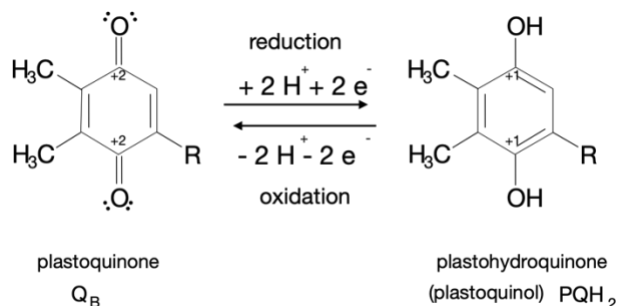
The four electrons released by the two water molecules will all be taken on, one by one, by the oxidized OEC catalyst.

Meanwhile the ionized electron lost from P680 is passed from molecule to molecule within Photosystem II. The passage of the electron through these molecules happens this way:

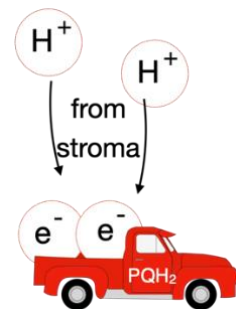
- The special chlorophyll molecule, P680, loses an electron: $P680 \rightarrow P680^+ + e^-$
- The ionized electron moves spontaneously to a nearby pheophytin molecule. (Pheophytin has a similar structure to chlorophyll.)
- When an atom or molecule gets an extra electron, you say it is reduced. The reduced pheophytin molecule then loses the electron to a nearby plastoquinone molecule (Plastoquinone A (Q_A)). Plastoquinone has a higher electron affinity (and therefore reduction potential) than pheophytin. A plastoquinone molecule will take on two electrons, one at a time – its two ketone sites ($C=O$) are reduced to alcohol sites ($C-OH$).
- The (now reduced) plastoquinone A molecule loses those two electrons to another nearby plastoquinone molecule, plastoquinone B (Q_B). This happens because when Q_B takes on the extra electron, it then takes it away from Photosystem II by leaving and diffusing through the thylakoid membrane.



When Q_B took on the two electrons (and two H^+ ions), its two ketone sites ($C=O$), became two alcohol sites ($C-OH$).



Q_B took two the H^+ ions from the stroma. Q_B is now a mobile electron carrier with a new name; plastoquinone (PQH_2) (aka plastoquinol). Its destination is a

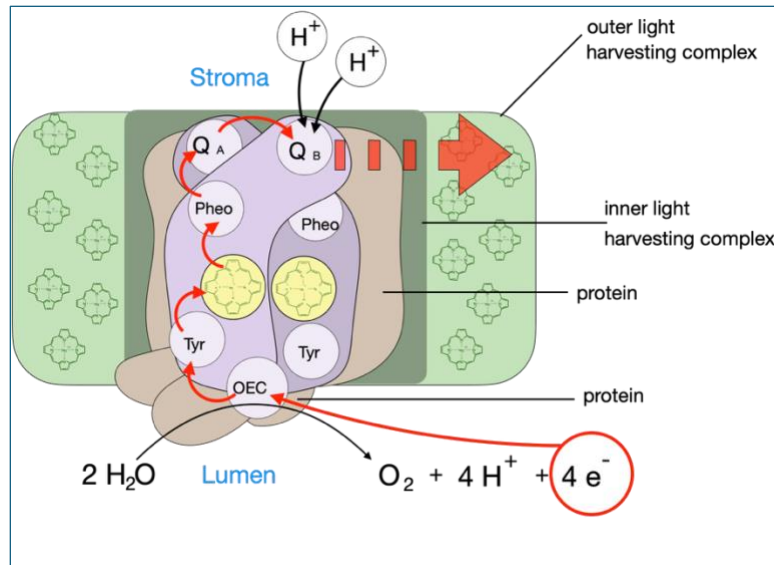


complex called the cytochrome b_6f complex.

Note also that when the plastoquinone loses its ketone groups ($C=O$) to alcohol ($C-OH$) groups, it also gains a stable aromatic ring (3 double bonds within a six-carbon ring).

The Light Dependent Stage of Photosynthesis Part II: Photosystem II

More Detail on Photosystem II



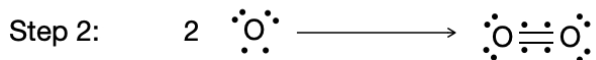
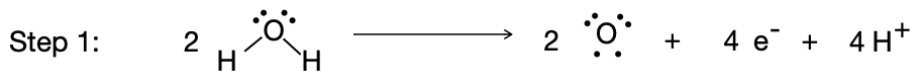
Photosystem II has two proteins in its centre. Each protein binds a copy of the electron transport chain (the tyrosine site of a protein, one of the special pairs of chlorophyll, pheophytin, and plastoquinone). There is only one copy of the OEC (4 Mn) catalyst; it's shared by both proteins.

Photosystem II is a multi-subunit enzyme and the only enzyme known in nature that can split water and release molecular

oxygen².

A Radical Problem for Photosynthesis

The splitting of water can proceed via these two steps:



Notice that a free oxygen atom (an oxygen radical) is produced in step 1. An oxygen radical is so reactive that it can do much damage to the protein molecules in Photosystem II (it can grab e^- from the protein molecule to form O^- and O^{2-}). The core protein in Photosynthesis II has a half-life of 8 hours because of this - and in less time when there is strong sunlight. There are enzymes present to repair and rebuild this protein (and others). But the radicals can also attack these enzymes. So, the leaf cells constantly repair or replace enzymes throughout the day. This repair is coded for by DNA, but the radicals also attack the DNA. The DNA in leaf cells is continuously repaired because of the radical damage (and also because of the damage from the UV rays of the sun).

The plant can expend the energy needed to keep up with all this repair and to keep photosynthesis under control. The oxidation of the Mn ions in the catalyst is done in

² Photosystem II. John Whitmarsh. Govindjee. Encyclopedia of Life Sciences. Macmillan Publishers. 2002

The Light Dependent Stage of Photosynthesis Part II: Photosystem II

stages which helps slow down the production of oxygen radicals. This helps keep the oxygen radicals contained within the catalyst until O_2 is formed³.

As well, there are carotenoid pigments in Photosystem II, and carotenoid pigments can bond to oxygen radicals and so keep them from reacting with other species.

On top of this, there are multiple feed-back loops in the chloroplast that shut down photosynthesis when it proceeds to quickly.

All these systems, and more, need to be in place for photosynthesis to work. If one part isn't working, photosynthesis cannot proceed. There's no model to explain how, then, plants were able to carry out photosynthesis before all this was place. An evolutionist would have to say it's a brute fact that it must have found a way. A brute fact is an unexplained scientific point that cannot be supported by any scientific explanation. Critics argue that brute facts make science and reason difficult to justify; others that there is no other rational choice but to accept their existence. The Bible supports the existence of brute facts, for example it says that God exists and created all this.

³ For a deeper look at this, see the article, Green power (photosynthesis) by Dr. Jonathan Sarfati, published 05 July 2006 in Creation.com. <https://creation.com/en/articles/gods-solar-power-plants-amaze-chemists>