3.2 Light-dependent reactions

The 'light' stage of photosynthesis: photolysis of water and photophosphorylation

The first stage, or set of reactions, involved in photosynthesis is called the **light-dependent** stage. The light-dependent reactions occur in the **thylakoid membranes** inside chloroplasts. It is the photosystems (which are made up of many photosynthetic pigments) embedded in these membranes which are of importance. For one set of light-dependent reactions to happen, two photosystems are used: **photosystem I** (PSI), which is found mainly on the intergranal lamellae, and **photosystem II** (PSII), which is found almost exclusively on the granal lamellae. The light-dependent stage is focused on converting light energy (trapped by pigments in the photosystems) into chemical energy.

Photolysis of water

The photosystem which is involved in the first part of this stage is actually photosystem II, as photosystem I is involved later on. PSII has an enzyme which, in the presence of light, splits a molecule of water into protons, electrons and oxygen.

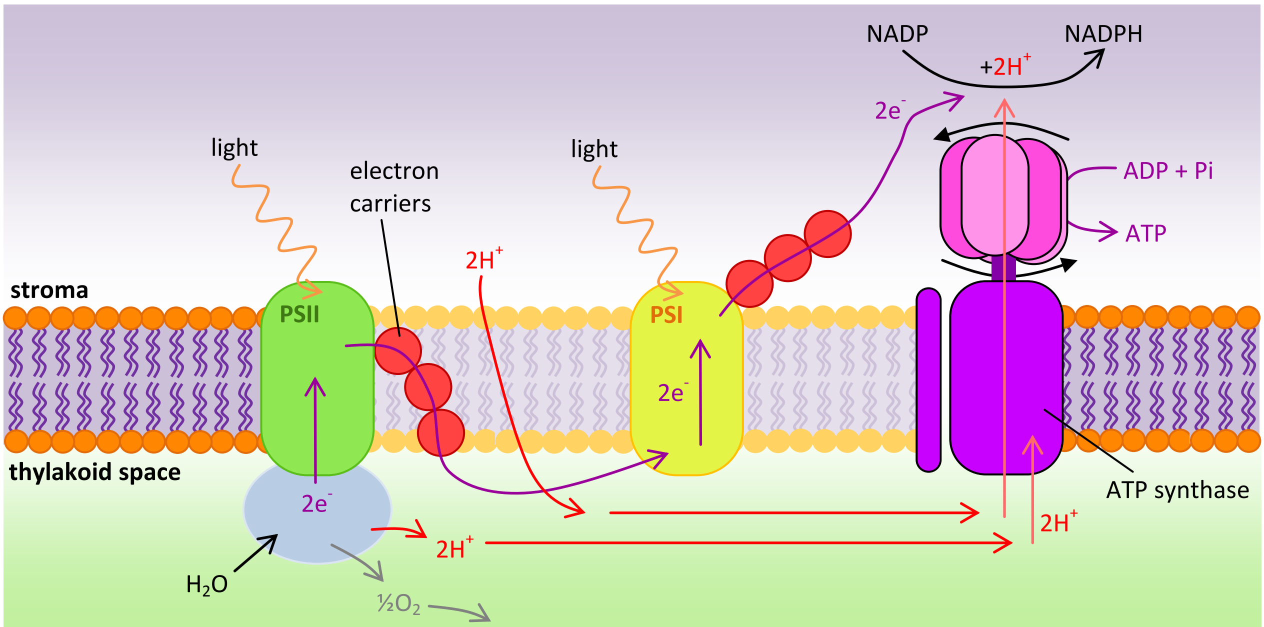
$$2H_2O \rightarrow 4H^+ + 4e^- + O_2$$

It is the protons and electrons produced which are of importance here. The oxygen is actually a waste product for this reaction. However, this **photolysis** (the splitting of a molecule using **photons**, or light particles) of water from the light-dependent reactions is seen as one of the most important reactions in life: the oxygen produced is the source of almost all of the oxygen in the atmosphere, which many organisms require to respire, and therefore live. Although a waste product in this reaction, plants use some of the oxygen produced to aerobically respire, but most of it leaves the leaves through the **stomata** (pores in the leaf surface where gaseous exchange may take place in plants).

Formation of ATP: chemiosmosis

The protons, or hydrogen ions, have two purposes. Firstly, they are used to generate **ATP** molecules by **chemiosmosis** (see 4.4 Electron transport chain for more details). In summary, protons diffuse across the thylakoid membrane through channel proteins which are associated with the enzyme **ATP synthase**, driving the rotation of part of the ATP synthase molecule, which combines a molecule of ADP (adenosine diphosphate) and an inorganic phosphate to form ATP.

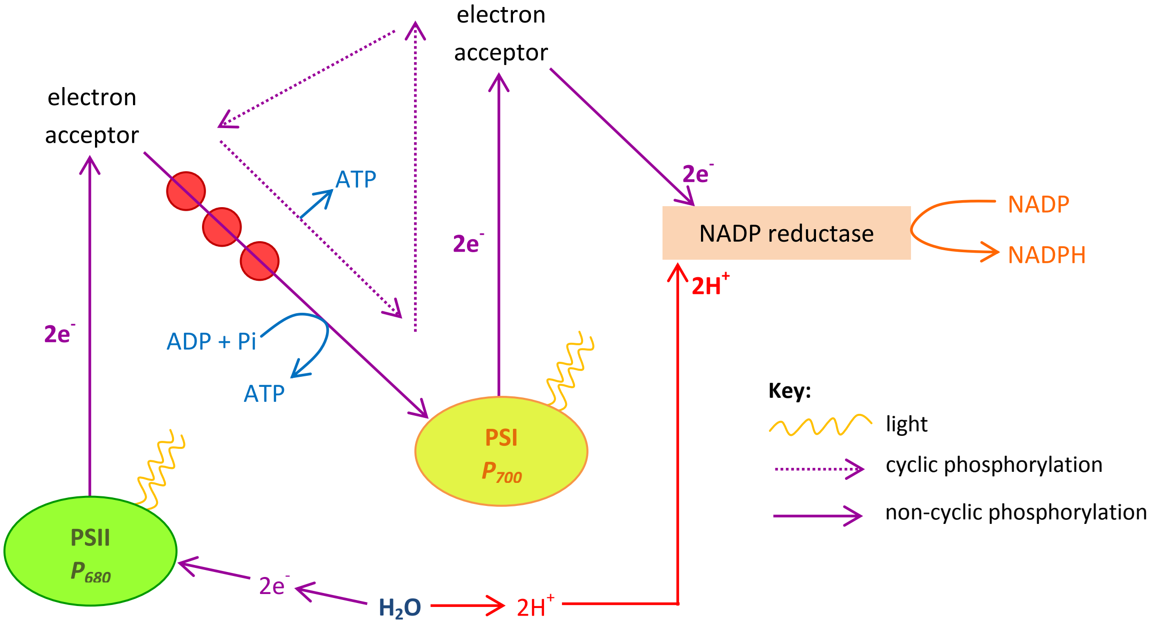
The protons then are accepted by the coenzyme **NADP** (nicotinamide adenine dinucleotide phosphate), alongside electrons, to form reduced NADP, or **NADPH** (also sometimes written $NADPH_2$). Reduced NADP is then used in the second stage of photosynthesis, the *light-independent reactions*.



The diagram above shows the photosystems I and II and the enzyme ATP synthase embedded in a thylakoid membrane. The blue area shows the photolysis of water, and the pathways of the electrons and protons produced. The oxygen may be used for aerobic respiration, but will usually leave the leaf through the stomata.

The Z-pathway

The series of reactions involved in the light-dependent stage are known collectively as the 'Z-pathway' because of the movement of electrons across the photosystems and thylakoid membrane.



1. In the presence of light, a molecule of water is split using an enzyme found within photosystem II, with a peak absorption of light wavelength 680nm (written P_{680}), into an atom of oxygen, as well as two electrons and two protons. The oxygen is a by-product which is not used in this reaction
2. The two hydrogen ions (protons) remain inside the thylakoid space, but the electrons are accepted by photosystem II when light is present, as the photons of light excite the electrons, so that they are then accepted by an **electron acceptor** and passed along various **electron carriers** (or **cytochromes**)
3. The movement of electrons along the thylakoid membrane between different cytochromes releases energy, which pumps protons across the membrane from the stroma into the thylakoid inner space
4. This creates a concentration gradient of protons over the membrane as they begin to accumulate, and so protons begin to diffuse back through to the stroma through channel proteins, which are associated with the enzyme ATP synthase. As proteins flow through the channel, the enzyme is activated, as the transport of the proton drives the rotation of the enzyme so that one ADP molecule and one phosphate group form a molecule of ATP – this is **photophosphorylation** (production of ATP using light energy)

There are two types of photophosphorylation which take place during the light-dependent reactions. One type involves only photosystem I (which has a peak absorption of 700, so is also called P_{700}), and the other both the photosystems.

Non-cyclic photophosphorylation

Essentially, the entire light-dependent stage is the process of **non-cyclic photophosphorylation**. This involves the flow of electrons from the photolysed water (the original electron donor) through the photosystems and cytochromes to the reduction of NADP. Non-cyclic photophosphorylation involves the steps 1-4 as seen above. In the diagram above of the Z-pathway, non-cyclic photophosphorylation can be seen producing ATP on the diagonal stroke of the Z-shape travelling towards photosystem I.

The electrons lost by photosystem I are replaced by the electrons from oxidised photosystem II, and the electrons donated from photolysed water replace those then lost by PSII. This flow of electrons is what makes the Z-pathway.

Cyclic photophosphorylation

Another type, **cyclic photophosphorylation** also occurs, but only at photosystem I. Electrons are lost from PSI as photons of light excite them, and passed around electron carriers and then back to the chlorophyll of PSI where they first came from, in a cycle. This movement of electrons does generate small amounts of ATP, but does not involve photolysis of water or reduce any NADP. The ATP produced may be used for other functions where energy is required.

The table below compares the different types of photophosphorylation to provide a summary:

	non-cyclic photophosphorylation	cyclic photophosphorylation
Which photosystems are involved?	PSI and PSII	PSI only
Does the reaction involve photolysis of water?	yes	no
Which molecule is the electron donor?	water	chlorophyll a (P_{700}) in PSI
Which molecule is the final electron acceptor?	NADP	chlorophyll a (P_{700}) in PSI
What are the products?	reduced NADP, ATP and oxygen	ATP only

Products of the light-dependent stage

Both cyclic and non-cyclic photophosphorylation drive the synthesis of ATP, so we know this is one product of the light-dependent stage. The other useful product for photosynthesis is NADPH (reduced NADP), which is an important molecule for the following stage (see 3.3 Light-independent reactions). Oxygen is a by-product which leaves the chloroplast and the leaf through the stomata, although some of the oxygen produced may be used for aerobic respiration.