

Understandings:

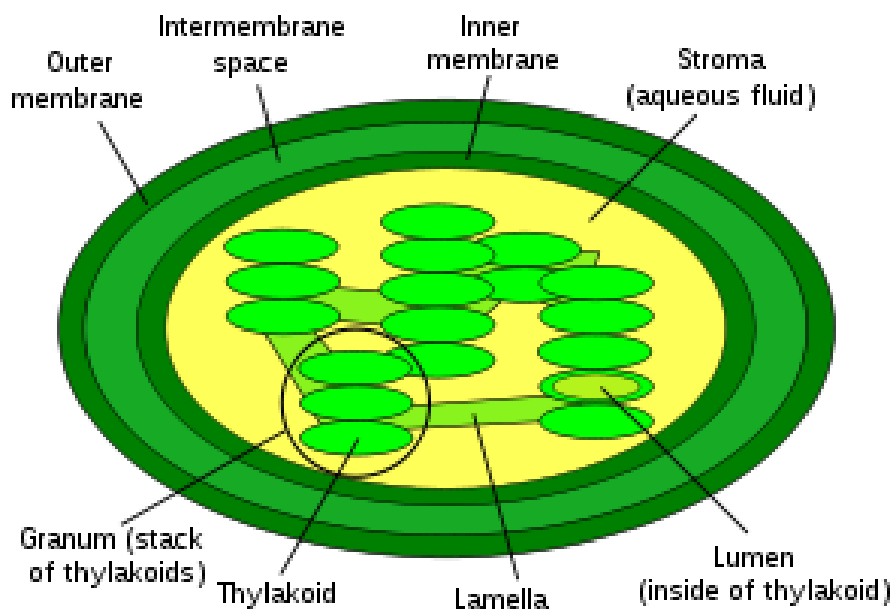
1. State the location of light-dependent reaction.

- Before digging in, it is important to have an overview, just like cellular respiration, in particular the order and the locations.

Photosynthesis occurs as light-dependent reaction → light-independent reaction.

We can see from here that light-independent reaction is dependent on the light-dependent reaction thus it cannot continue forever in darkness.

The location of light-dependent reaction is thylakoid space/lumen. This is the space covered in thylakoid membrane, which is inside inner membrane of chloroplast and further surrounded by outer membrane of chloroplast.



2. Outline the processes and products of light-dependent reaction.

- The main idea of light-dependent reaction is to build up energy for the light-independent reaction.

The processes are:

- Photolysis
- Photoactivation
- Electron chain transport
- Chemiosmosis
- ATP synthesis
- Reduction of NADP

We can see that the light energy is used to make ATP and reduced NADP (slightly different from NAD^+).

3. State the location of light-independent reaction, aka Calvin cycle.

- The light-independent reaction takes place in the stroma.

Just like the matrix, stroma contains lots of enzymes. But what does the Calvin cycle do?

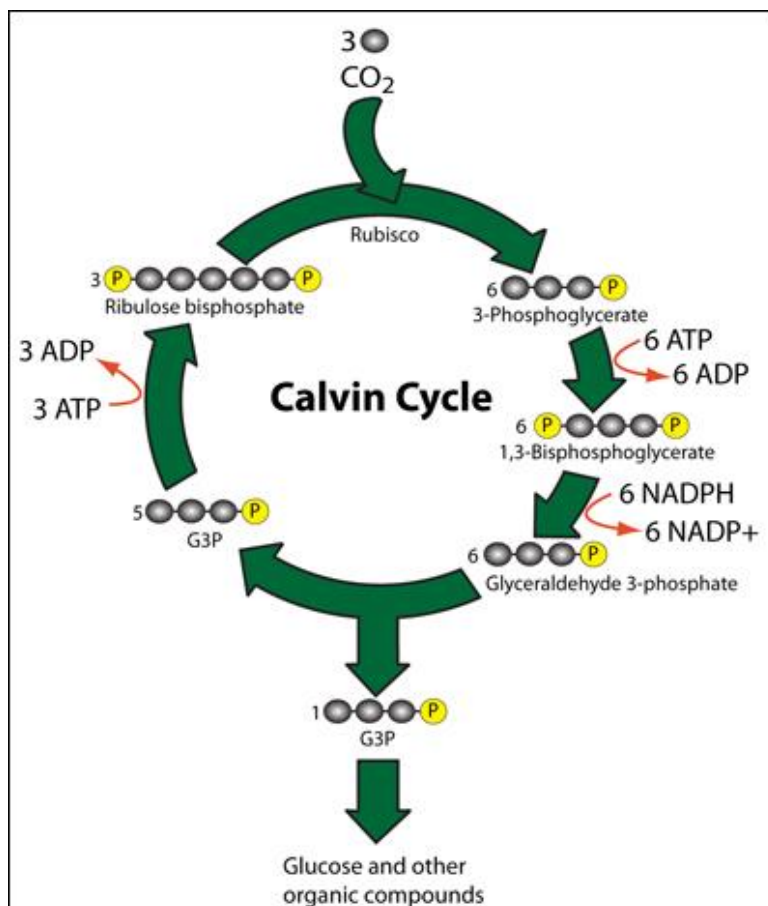
Well, it is an anabolic metabolism that needs energy to make macromolecules like sugar!

4. Outline the processes and products of light-independent reaction.

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The processes are:

- Carbon fixation
- Carboxylation of RuBP to produce triose phosphate
- Production of triose phosphate (glyceraldehyde 3-phosphate).
- Consumption of ATP and NADPH (reduced NADP) to produce sugar and regenerate RuBP

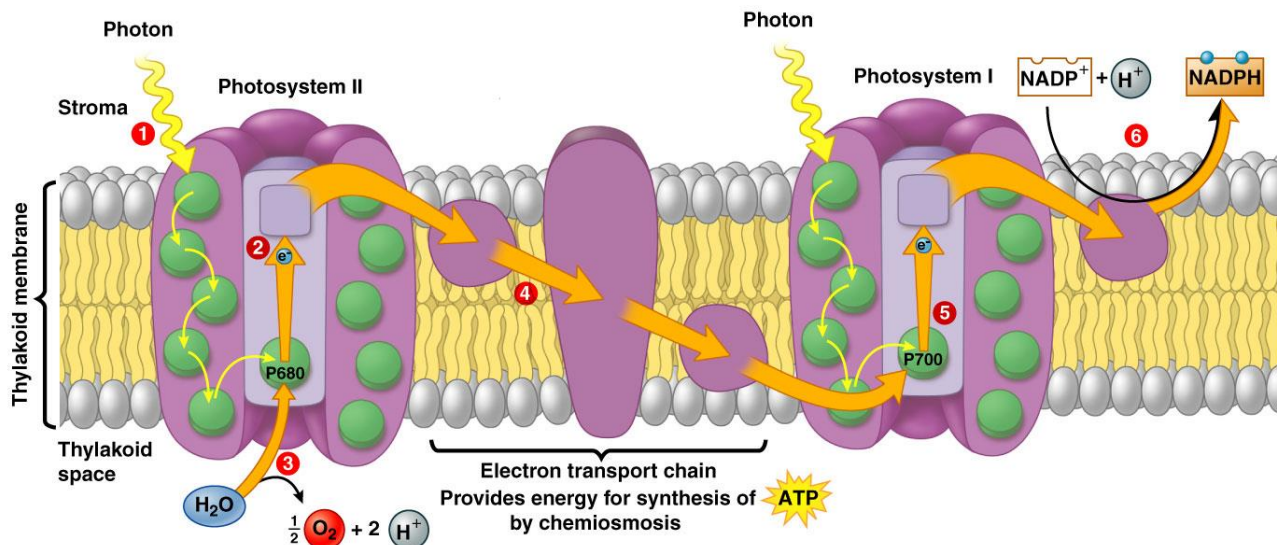


5. Explain photoactivation.

- As HL level students, we should study relatively in-depth of each of the processes.

Photoactivation is just as it sounds. We use photons from the light to activate. But activate what? Well, the photons are harvested on small structures called photosystems (looks like a paprika) on the thylakoid membrane.

There are two types of photosystems: photosystem 2 and photosystem 1. Photosynthesis always starts in photosystem 2. The reason is because photosystem 1 was discovered first.



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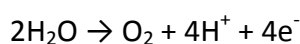
We have three structures in photosystem. The surrounding structures in purple are the light harvesting arrays and they contain pigments that absorb light. This is also what mainly gives colour.

The energy is transferred via pigments (chlorophyll usually) into the next structure called reaction center (grey structure in middle). Here, the energy excites a special chlorophyll (P680) and makes it release 2 e⁻.

Then, the electrons are accepted by an acceptor called plastoquinone. This happens twice so we get 2 reduced plastoquinone and two chlorophylls with +2 charge each.

6. Explain photolysis.

- The two chlorophylls are now desperate for electrons! They are therefore very strong oxidizing agents. Who do they then oxidize? It is the water. Energy from light splits water.



They have recovered their lost 4 electrons (2 each) and diffuse oxygen as “waste” product.

Note that this happens in the thylakoid space.

7. Explain the electron transport chain in plants.

- Now, we should utilize the plastoquinone somehow and this is done in the electron transport chain. Remember, this is a part of the light-dependent reaction and the purpose of light-dependent reaction is to accumulate ATP and reduced NADP⁺ (NADPH + H⁺) for light-independent reaction. In fact, it is called photophosphorylation instead of oxidative phosphorylation.

Just like cellular respiration, we need to make a potential gradient.

The reduced plastoquinone is hydrophobic, hence it moves in between the bilayer membrane. It then transfers the electrons only to the starting point of electron chain transport. Plastoquinone does not move all the way to photosystem 1! Then, just like before, the electron carriers does its job with transferring electrons along the membrane and use the energy to produce concentration gradient of H⁺.

8. Explain the photon gradient.

- Explained above.

9. Explain chemiosmosis.

- Just like in the mitochondrion, H⁺ moves from high gradient (thylakoid space) out to stroma. It passes the ATP synthase and phosphorylates ADP to ATP.

One difference is that in mitochondrion, H⁺ moves from intermembrane space into matrix, while in chloroplast, H⁺ moves from thylakoid (instead of its intermembrane space) out to stroma.

It can be slightly confusing. But it makes sense if you think about the volume. Volume of thylakoid is small and so is the intermembrane space in mitochondrion.

10. Explain the reduction of NADP in relation to Photosystem 1.

- This is the last step in light-dependent reaction. We know that the plastoquinone delivers electrons to electron transport chain to pump H⁺, but what happens to the electrons?

These get carried by plastocyanin to the photosystem 1. The electrons are at low energy, thus we use photoactivation to activate them again! Now that we have excited the electrons again, these are used to reduce NADP⁺ to NADPH + H⁺.

So photosystem 2 → plastoquinone → via cytochrome complex (electron transport chain) → plastocyanin → photosystem 1

However, sometimes, there is not enough NADP⁺ to be reduced. If that is the case, a molecule called ferredoxin (irons – Fe that are good at redox, hence ferredoxins) transfers the electrons back to electron transport chain. Electrons will move back to photosystem 1 and pump more H⁺ to produce more ATP instead of using the electrons to reduce NADP⁺.

11. Explain carbon fixation.

- Now we enter the light-independent reaction.

Carbon fixation means to just capture carbon, and the form all photosynthetic organisms capture carbon is CO₂. They are diffused into the stroma (the liquid, and corresponds to the matrix in mitochondrion). Then simply, this carbon dioxide reacts with ribose biphosphate (5 carbon molecule) to form two three-carbon molecules called glycerate 3-phosphate.

This is catalysed by the enzyme ribulose biphosphate carboxylase, a.k.a. Rubisco. We can imagine that there are many of these in the stroma to maximize efficiency.

Note that all of carbon dioxide reacts with the ribose thus does not form oxygen. Only place where oxygen is formed is in at photosystem 2 where electron is needed to give to the oxidized pigments.

12. Explain the role of reduced NADP and ATP in the Calvin cycle.

- The product so far is glycerate 3-phosphate. However, carbohydrates (the product that we want) has H:O ratio of 2:1, but glycerate 3-phosphate has lower hydrogen ratio.

Therefore, hydrogen must be added. This is done by using 1 ATP molecule and 1 NADPH + H⁺ for each glycerate. This gives us a triose phosphate.

Since we had two of glycerate, well, you can do the math by simply multiplying with 2.

Note that in cellular respiration, we moved the opposite direction. We oxidized triose phosphate to form glycerate 3-phosphate!

13. Explain the role of triose phosphate.

- Now, triose phosphate can do two things. It can either regenerate RuBP molecules or form 6 chain sugar molecules.

Now, we have to do some mathematics. Triose phosphate is a 3 carbon molecule. RuBP is a 5 carbon molecule. So if we have 5 triose phosphate we can make 3 RuBP. But we can only get even number of triose phosphate (since 6 carbon chain splits to two), so 6 is the closest one. Thus three Calvin cycles produce 6 triose phosphates, whereof for 5 are used for making 3 RuBP and leaves 1 spare triose phosphate. The next three cycles produce 6 triose phosphates again and does the same thing.

Therefore if we have six Calvin cycles, we get 6 RuBP molecules and two spare triose phosphate that can be combined to make glucose!

14. Explain how RuBP are regenerated.

- Yes, we have explained this above. Just know that we need 3 ATP molecules to regenerate because we are making 3 RuBP.

15. Describe the structure and function of chloroplast.

- Chloroplasts have an outer membrane called chloroplast envelope. This is to make a closed system specialized for photosynthesis.

Internal membrane called thylakoids full of pigments. This is to maximize surface area. There are small fluids inside the membranes.

Many layers of thylakoid are called grana.

The “cytosol” or “matrix” of chloroplast is called stroma. There are many enzymes there. We might see some starch grains or lipid droplets when there is photosynthesis.

Applications and skills:

1. Understand Calvin’s experiment on elucidate (explain in detail) the carboxylation (adding carbon) on RuBP.

- Like many of the experiments with DNA, this uses radioactive element, in this case carbon 14. This way, we can trace the radioactive carbon and see the steps of carboxylation.

1. First, glycerate 3-phosphate has highest radioactivity. Thus this is the first step.
2. Then, the radioactivity for glycerate molecule decreases while it increases for triose phosphate and other sugar phosphates. This means that there is a conversion taking place.
3. To calculate the rate of formation of glycerate, calculate the rate of increasing radioactivity of triose phosphate because they are essentially complementary to each other.

2. Annotate the structures of chloroplast and how their structure is adapted for their function.

- Chloroplasts have thylakoids with high surface area, stacked in structures called grana. This maximizes the light absorption.

The volume in thylakoids is small for protein gradients to be built fast. This makes ATP production fast that is going to be used for light-independent reaction.

The stroma contains many enzymes to catalyze Calvin cycle and also distributed thylakoids to have easy access to ATP and NADPH.

TOK:

1. The lollipop experiment used to work out the biochemical details of the Calvin cycle shows considerable creativity. To what extent is the creation of an elegant protocol similar to the creation of a work of art?