Photosynthesis

Key concepts

10.1 PHOTOSYNTHESIS CONVERTS LIGHT ENERGY TO THE CHEMICAL ENERGY OF FOOD.

10.2 THE LIGHT REACTIONS CONVERT SOLAR ENERGY TO THE CHEMICAL ENERGY OF ATP & NADPH.

10.3 THE CALVIN CYCLE USES THE CHEMICAL ENERGY OF ATP & NADPH TO REDUCE CO2 TO SUGER.

❖ Overview:

1. life on earth is solar powered.
2. Photosynthesis: is to convert the light energy to chemical energy that is stored in sugar and other organic molecules.
3. We have 2 types of organisms depending on their nutrition:

Autotrophs	***Heterotrophs***
Self-feeders; they sustain themselves without eating anything derived from other living beings	Other-feeding; they obtain their organic material by the second major mode of nutrition. Unable to make their own food, they live on compounds produced by the other organisms.
They are the ultimate source of organic compounds for all non-autotrophic organisms	-
Producers of the biosphere	Biosphere consumers
Plants, algae, certain other protisits, and some prokaryotes.	Most fungi, humans, animals….etc.

Photosynthesis

1. <u>*Concept 10.1:*</u> photosynthesis converts light energy to the chemical energy of food:

Photosynthesis emerges from structural organization in the cell, and they will be discussed as the following:

1) <u>*Chloroplasts:*</u>

They are the green parts of the plants; mostly the leafs, green stems and uni-ripened fruit. They are found mainly in **the cells of mesophylls** (the tissues in the interior of the leaf).

لتسهيل الشرح رح نمشي بالطريقة التّالية:

Note: the **leafs** contains:

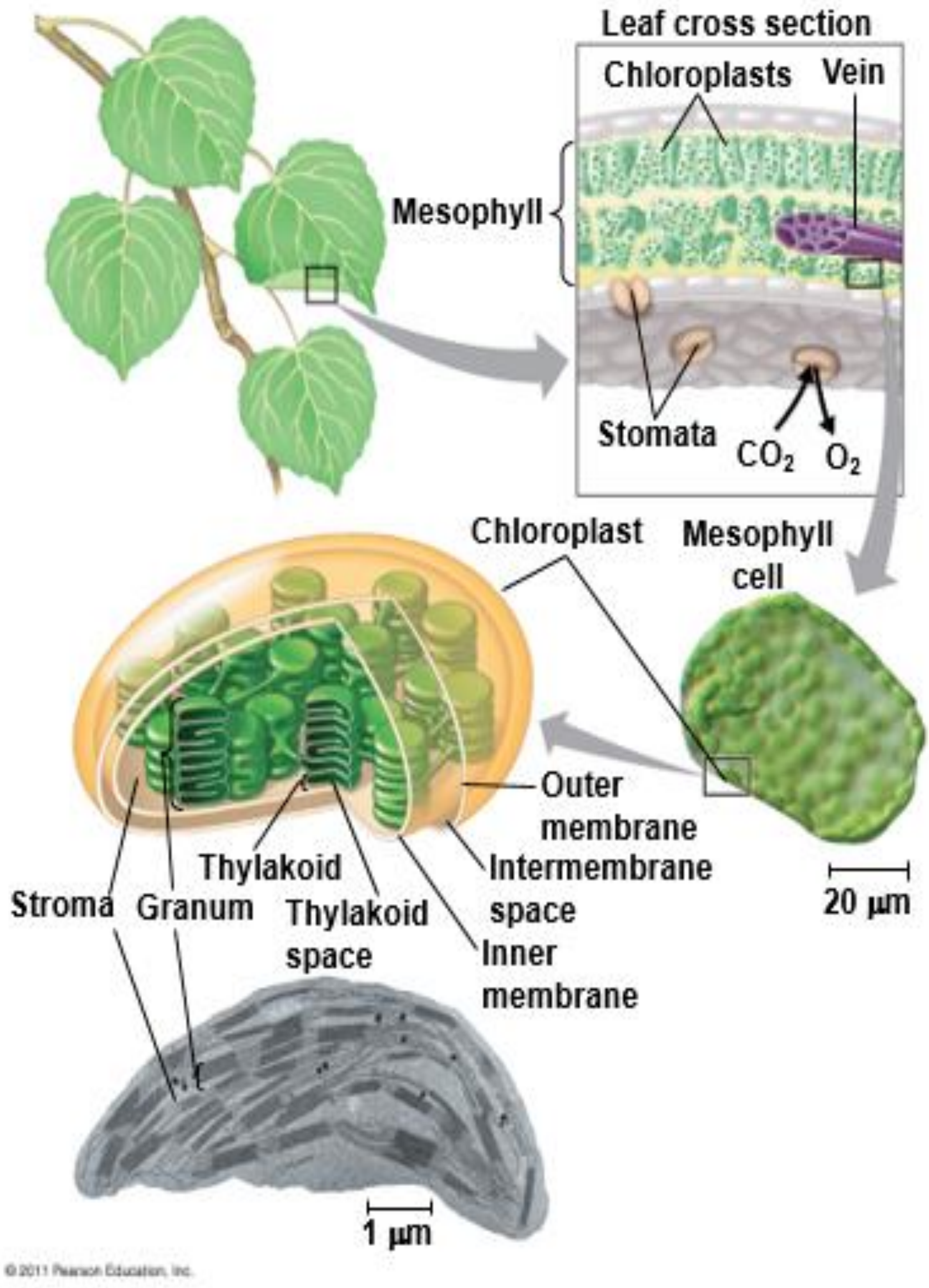
- **Stomata (singular: stomata):** microscopic pores that works as an entrance for CO_2 and exit of O_2.
- **Veins:** to deliver water from roots to the leaves, also export sugar to roots and other non-photosynthetic parts of the plant.
- **Mesophyll:** the tissue in the anterior part of the leaf, it typically has 30-40 chloroplasts.

- Now let us talk about <u>***CHLOROPLASTS***</u>:

  Parts of it:

  1. **Stroma:** it is the dense fluid surrounded by 2 membranes (envelope).
  2. **Thylakoid:** suspended with in the stroma, and it is a third membrane system made up of <u>***sacs***</u>. Which segregates the stroma from <u>***the thylakoid space***</u> inside these sacs.in some places, thylakoid sacs are stacked in columns called <u>***grana (singular, granum).***</u>
  3. **Chlorophyll**: the green pigment that gives leaves their color, resides in the thylakoid membranes of the chloroplast. It is the light energy absorbed by chlorophyll that drives the synthesis of organic molecules in the chloroplast.

Photosynthesis



Photosynthesis

2) Tracking Atoms through Photosynthesis: scientific inquiry

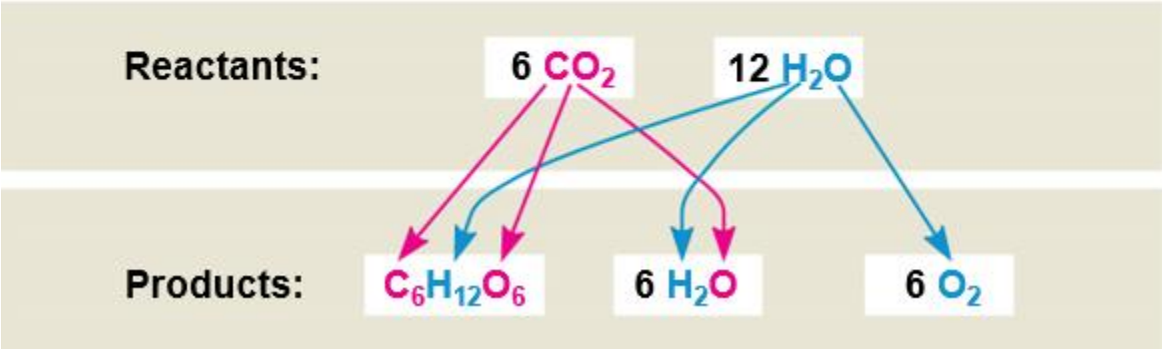
In the presence of light, the green parts of plants produce organic compounds and oxygen from carbon dioxide and water.

- Photosynthesis is a complex series of reactions that can be summarized as the following equation using the molecular formula:

  6 CO2 + 12 H2O + Light energy C6H12O6 + 6 O2 + 6 H2O

- **The splitting of water:**

  Chloroplasts split H_2O into hydrogen and oxygen, incorporating the electrons of hydrogen into sugar molecules and releasing oxygen as a by-product.



- **Photosynthesis as a Redox Process:**
  - Photosynthesis reverses the direction of electron flow compared to respiration.
  - Photosynthesis is a redox process in which H_2O is oxidized and CO_2 is reduced.
  - Photosynthesis is an endergonic process; the energy boost is provided by light.

Photosynthesis

3) THE TOW STAGES OF PHOTOSYNTHESIS: A Preview

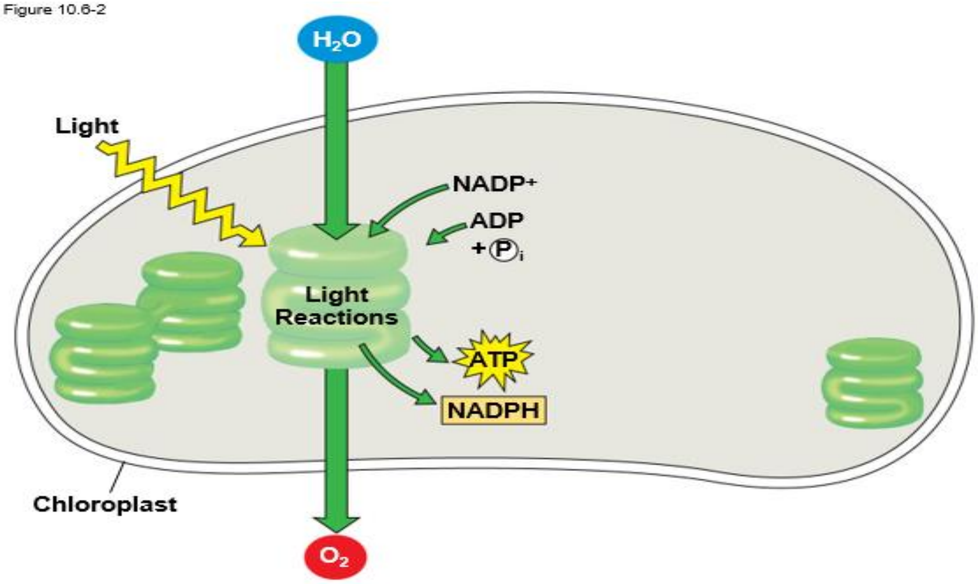
   Photosynthesis is not a single process, but tow processes, each with multiple steps:

   1. Light reaction. → the photo part
   2. Calvin cycle. → the synthesis part

1. Light reaction:

- It converts solar energy to chemical energy.
- Water is split → Hydrogen ions, H^+ , also O_2 as giving product.
- So, how the process is done:
  1- Water split to hydrogen ions and H^+, and also O_2 as a product.
  2- Light inters the chloroplasts and react with the chlorophylls to:
  Transfer the electrons and hydrogen ions (from the water) to an **acceptor** called **$NADP^+$ (nicotinamide adenine dinucleotide phosphate).**
  3- The light reaction
     a. uses **solar power** to reduce **$NADP^+$** in to **NADPH** by adding a pair of electrons along with an H^+.
     b. uses **chemiosmosis** to power the addition of a phosphate group to ADP. → ADP + phosphate group = ATP, so it generates ATP. (this process is called **<u>photophosphorylation</u>**).

Figure 10.6-2



So as a summary for the light reaction:

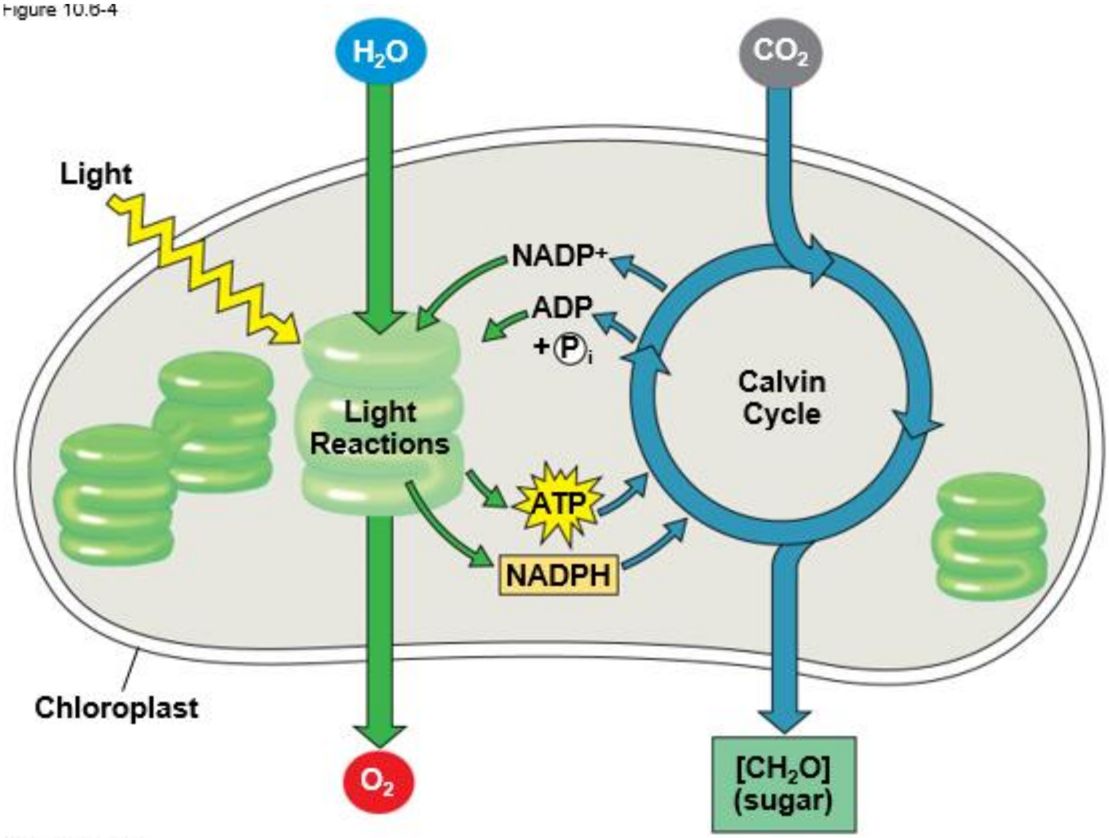
1. **Light energy is initially converted to chemical energy in the form of 2 components: 1) NADPH "a reducing power". 2) ATP.**
2. **It doesn't produce sugar.**

2. Calvin cycle:

How it is done:

1- Incorporate CO2 from the air into organic molecules already present in the chloroplast (this is called carbon fixation).
2- Reduces the fixed carbon to carbohydrate by the addition of electrons (by NADPH), also it uses ATP as a source of chemical energy.
3- The products are → ADP+ + NADP+ + phosphate group + CH2O + sugar) .

Figure 10.6-4



Photosynthesis

	Light reaction	Calvin cycle
Place	Thylakoid	Stroma
Need to light	It works by the power of light (solar power)	Called the dark reaction or light independent reactions, because none of the steps requires light *directly.*
Inputs	H_2O, light, ADP^+, $NADP^+$, phosphate group.	CO_2, ATP, NADPH.
Products	ATP, NADPH, O_2	ADP^+, $NADP^+$, phosphate group, CH_2O, and sugar.

NOTE: The Calvin cycle happens in the daylight (but don't require light), for only then can the light reactions provide the NADPH and ATP that the Calvin cycle requires.

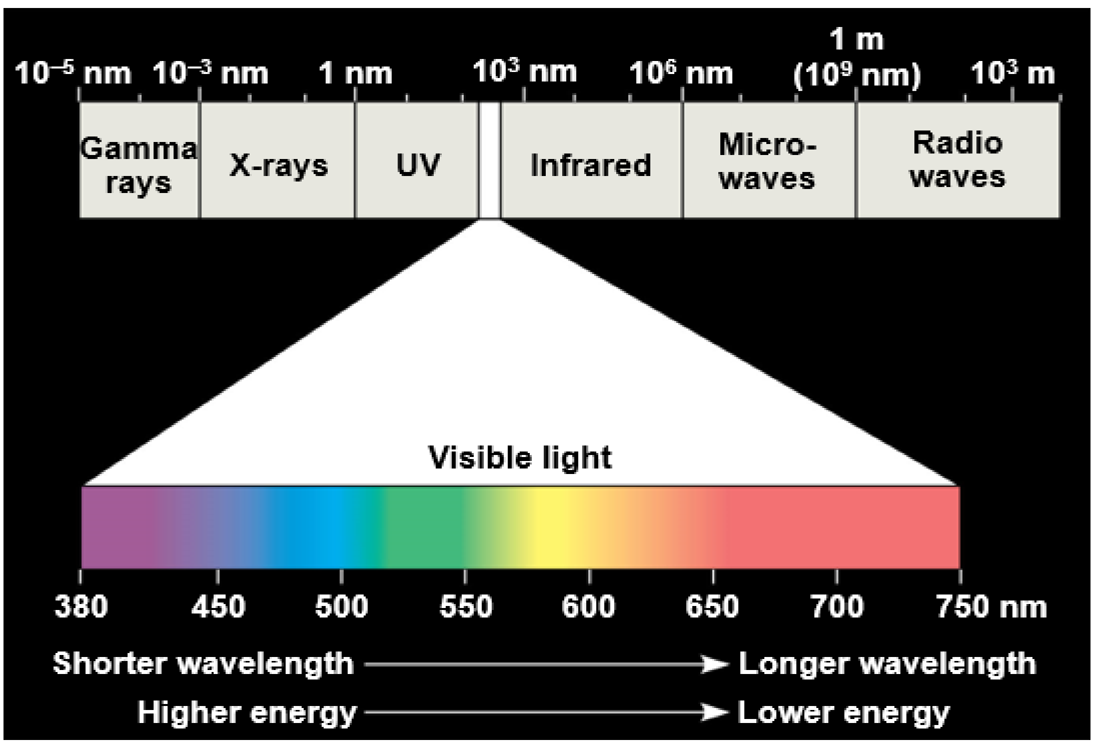
Concept check 10.1:

1. **How do the reactant molecules of photosynthesis reach the chloroplasts in leaves?**
2. **How did the use of an oxygen isotope help elucidate the chemistry of photosynthesis?**
3. **What if: The Calvin cycle requires ATP and NADPH, products of the light reactions. If a classmate asserted that the light reactions don't depend on the Calvin cycle and, with continual light, could just keep on producing ATP and NADPH, how would you respond?**

→ check appendix A for suggested answers.

Concept 10.2: the light reactions convert solar energy to chemical energy of ATP and NADPH

1) **The nature of light:**
   a. **Light** is a form of **electromagnetic energy**, also called **electromagnetic radiation**.
   b. Like other electromagnetic energy, light travels in rhythmic waves.
   c. **Wavelength** is the distance between crests of waves, that determines the type of electromagnetic energy.
   d. **The electromagnetic spectrum** is the entire range of electromagnetic energy, or radiation.
   e. Visible light consists of wavelengths (including those that drive photosynthesis) that produce colors we can see.
   f. Light also behaves as though it consists of **discrete particles, called photons**.



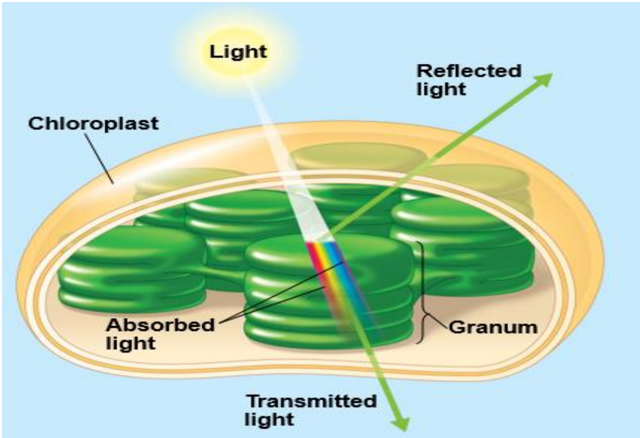
The electromagnetic spectrum

The white light is a mixture of all wave lengths of visible light.

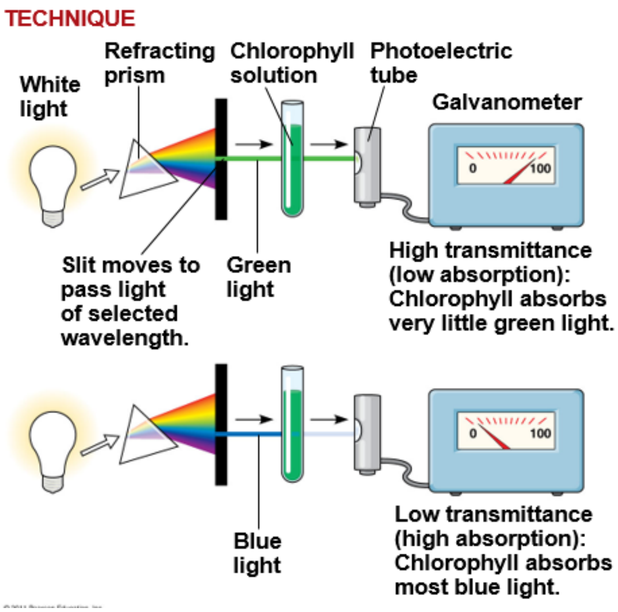
Note: although the radiates the full spectrum of electromagnetic energy, the atmosphere acts like a selective window, allowing the visible light to pass through while screening out the substantial fraction of other radiation. (the part of the spectrum we can see –visible-light- is also the radiation that drives photosynthesis.

Photosynthesis

2) Photosynthetic pigments: the light receptors
   - When light meets matter, it may be reflected, transmitted, or absorbed.
   - Pigments are substances that absorb visible light.
   - Different pigments absorb different wavelengths.
   - Wavelengths that are not absorbed are reflected or transmitted.



   - Leaves appear green because chlorophyll reflects and transmits green light.
   - If a pigment absorbs all wavelengths, it appears ***black***.



- The ability of a pigment to absorb various wavelengths of light can be measured with an instrument called ***"spectrophotometer".***

- ***How?????***

(This machine sends light through pigments and measures the fraction of light transmitted at each wavelength).

- An **absorption spectrum** is a graph plotting a pigment's light absorption versus wavelength.
- The **absorption spectrum** of **chlorophyll** a suggests that <u>violet-blue and red light work best for photosynthesis.</u>
- An **action spectrum** profiles the relative effectiveness of different wavelengths of radiation in driving a process.
- **Chlorophyll a** is the main photosynthetic pigment.
- **Accessory pigments**, such as **chlorophyll b**, broaden the spectrum used for photosynthesis.
- **Accessory pigments** called **carotenoids** absorb excessive light that would **damage** chlorophyll.

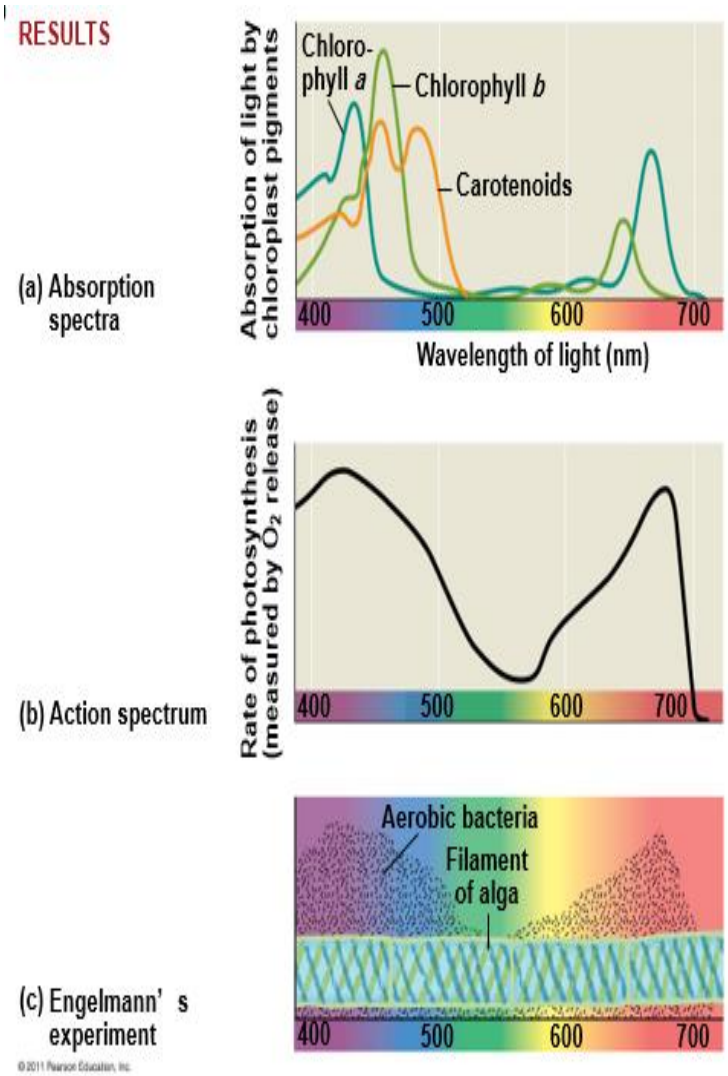
Photosynthesis

Note:

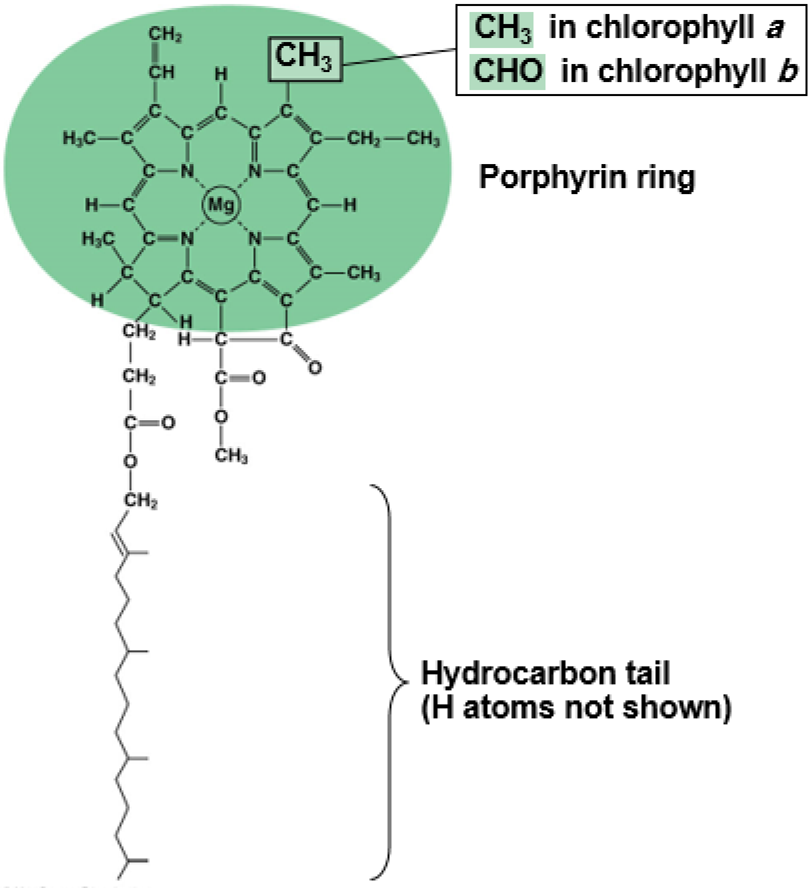
1. **The spectrum of chlorophyll suggests that the violet-blue and red light work best for photosynthesis, since they are absorbed, while green is the least effective color.**

❖ **Notes in the photo:**

I. The action spectrum of photosynthesis was first demonstrated in 1883 by Theodor W. Engelmann
II. In his experiment, he exposed different segments of a filamentous alga to different wavelengths
III. Areas receiving wavelengths favorable to photosynthesis produced excess O2
IV. He used the growth of aerobic bacteria clustered along the alga as a measure of O2 production
V. Chlorophyll a is the main photosynthetic pigment
VI. Accessory pigments, such as **chlorophyll b**, broaden the spectrum used for photosynthesis
VII. Accessory pigments called **carotenoids** absorb excessive light that would damage chlorophyll



Photosynthesis



the photo shows the difference between **chlorophyll a & chlorophyll b.**

they differ only in one of the functional groups bonded to the porphyrin ring.

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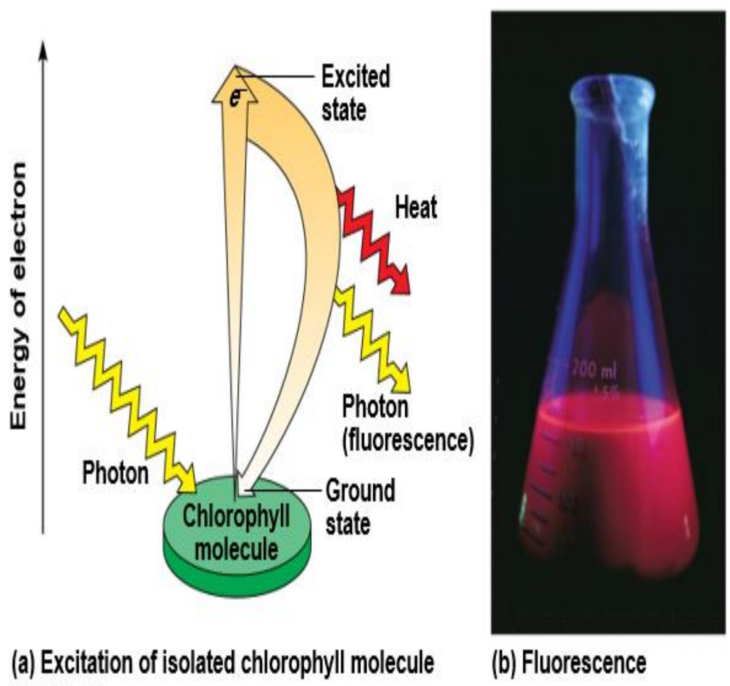
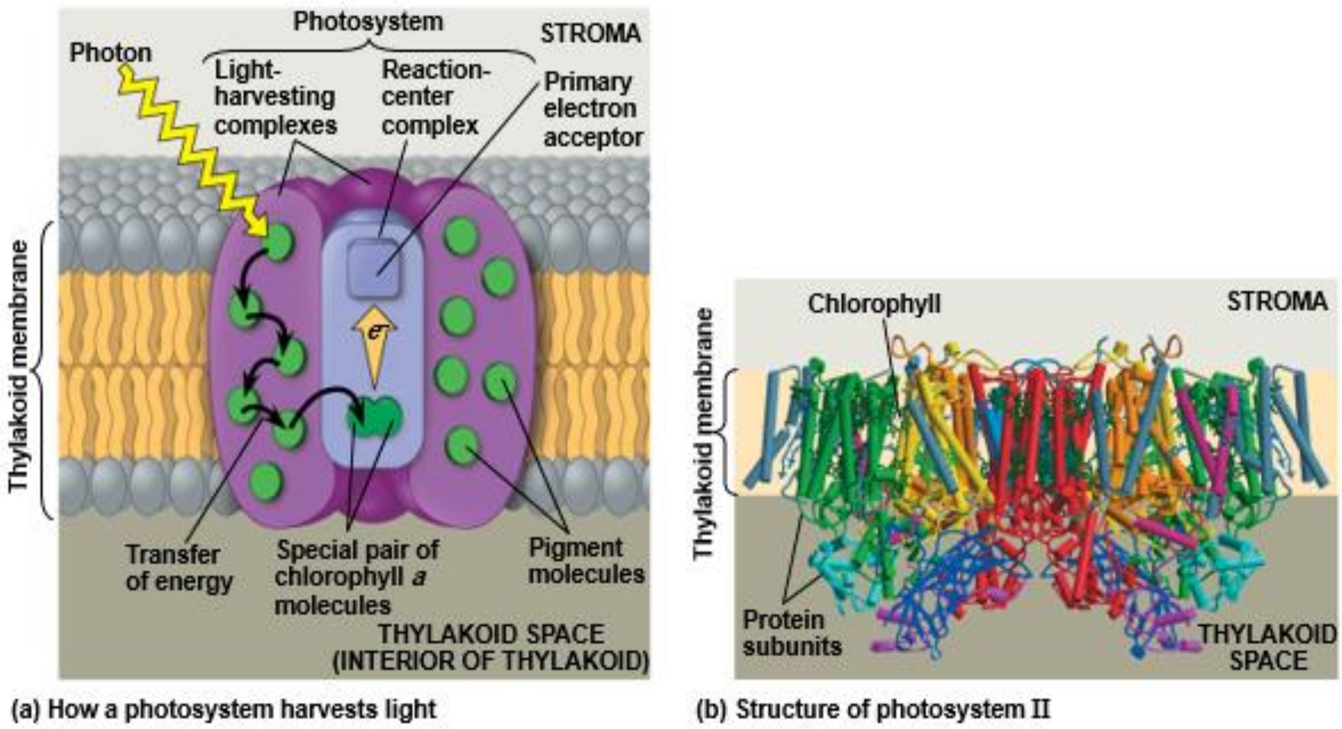
3) Excitation of Chlorophyll by Light:

- When a pigment absorbs light, it goes from a ground state to an excited state, which is unstable.
- When excited electrons fall back to the ground state, photons are given off, an afterglow called fluorescence.
- If illuminated, an isolated solution of chlorophyll will fluoresce, giving off light and heat.



4) A Photosystem: A Reaction-Center Complex Associated with Light-Harvesting Complexes

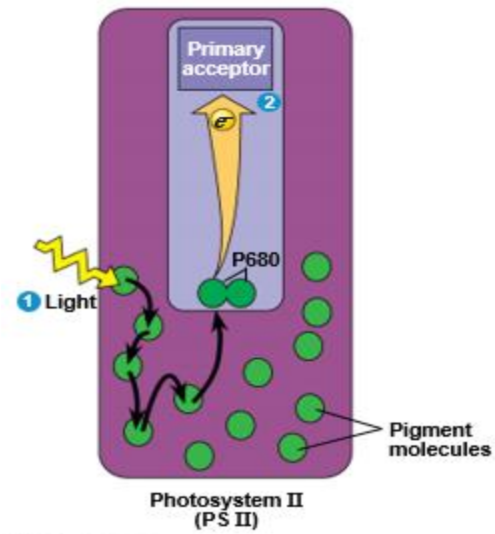
- A photosystem consists of a reaction-center complex (a type of protein complex) surrounded by light-harvesting complexes
- The light-harvesting complexes (pigment molecules bound to proteins) transfer the energy of photons to the reaction center



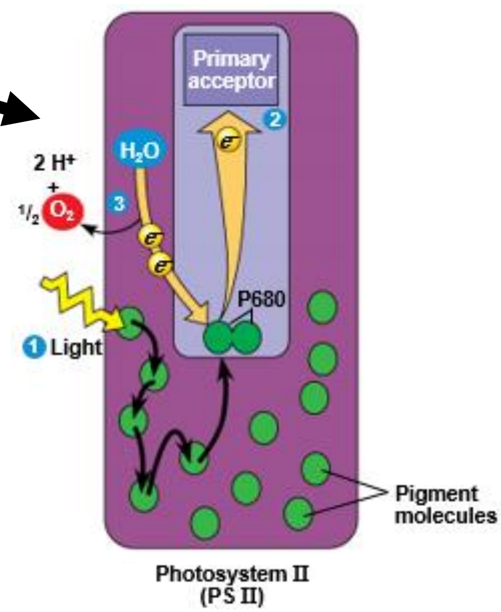
- **A primary electron acceptor** in the reaction center accepts excited electrons and is reduced as a result.
- **Solar-powered transfer** of an electron from a chlorophyll a molecule to the primary electron acceptor is the first step of **the light reactions**.
- There are two types of photosystems in the thylakoid membrane
- Photosystem II (PS II) functions first (the numbers reflect order of discovery) and is best at absorbing a wavelength of 680 nm
- The reaction-center chlorophyll a of PS II is called P680
- Photosystem I (PS I) is best at absorbing a wavelength of 700 nm
- The reaction-center chlorophyll a of PS I is called P700

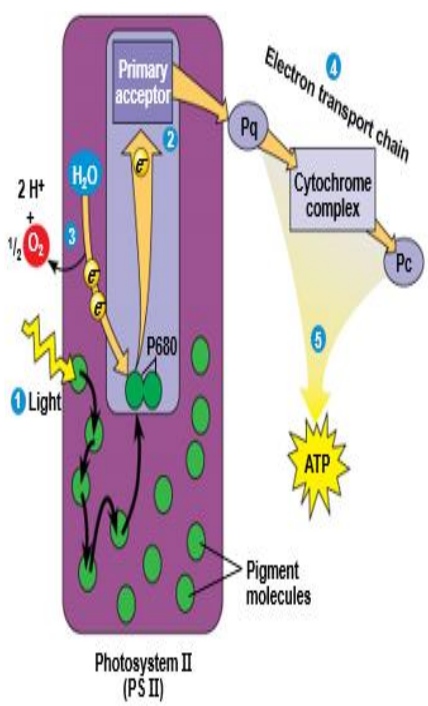
5) Linear Electron Flow:

I. During the light reactions, there are two possible routes for electron flow: cyclic and linear.
II. Linear electron flow, the primary pathway, involves both photosystems and produces ATP and NADPH using light energy.
III. A photon hits a pigment and its energy is passed among pigment molecules until it excites P680.
IV. An excited electron from P680 is transferred to the primary electron acceptor (we now call it P680+).



I. P680+ is a very strong oxidizing agent.
II. H2O is split by enzymes, and the electrons are transferred from the hydrogen atoms to P680+, thus reducing it to P680.
III. O2 is released as a by-product of this reaction.

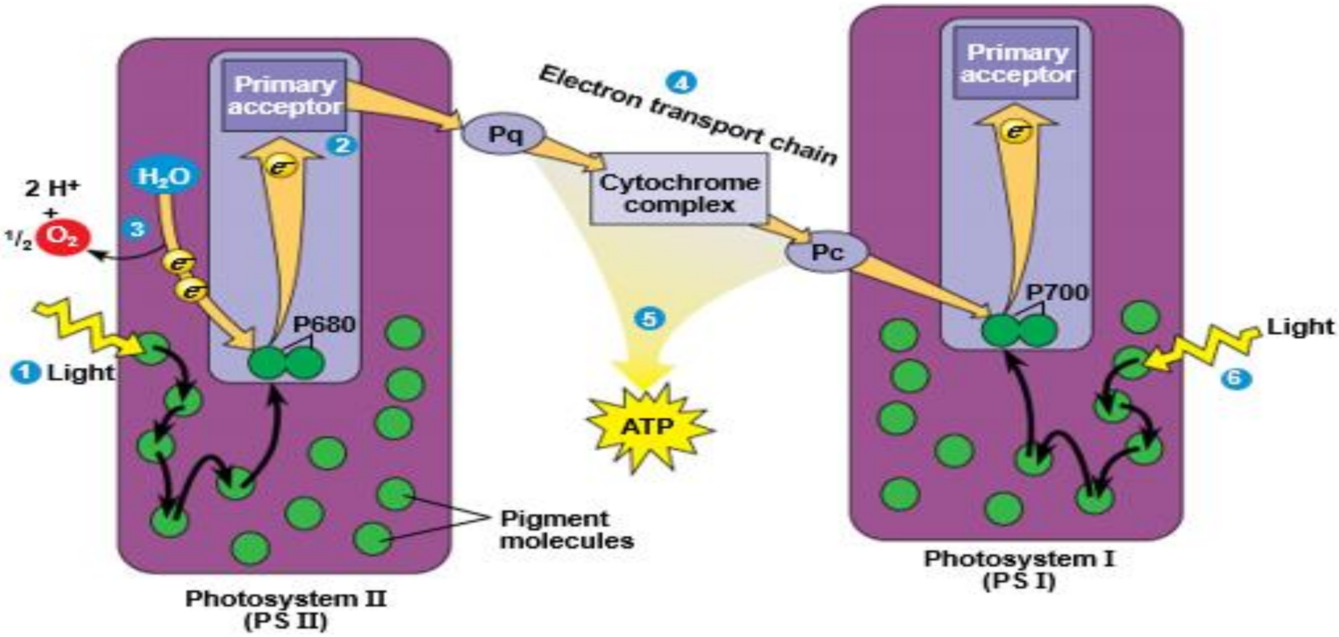




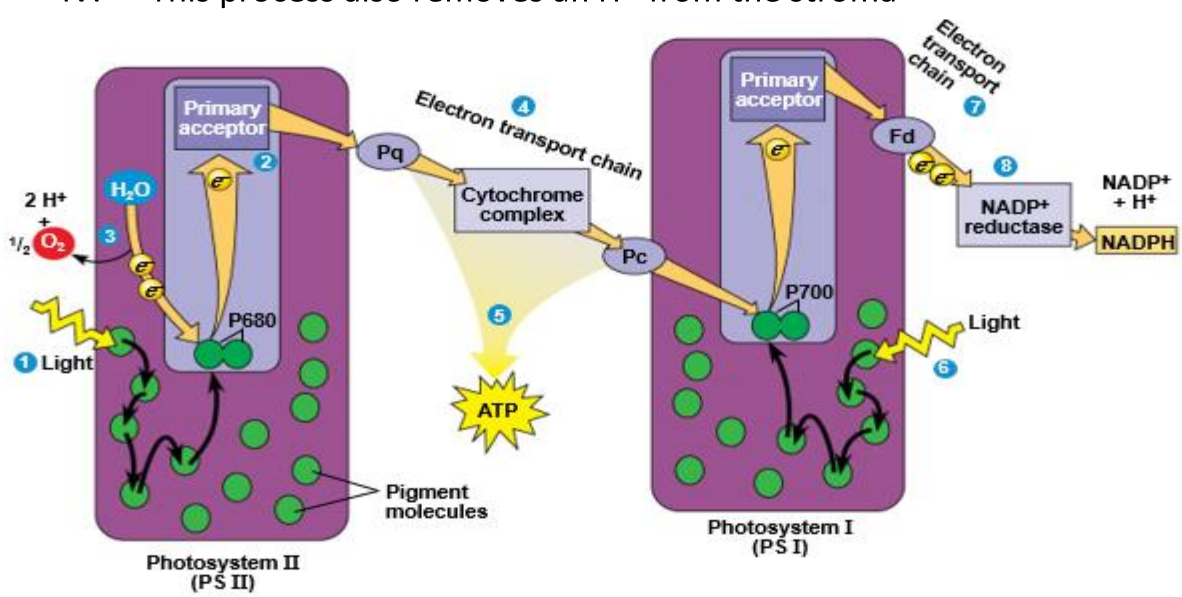
I. Each electron "falls" down an electron transport chain from the primary electron acceptor of PS II to PS I.
I. Energy released by the fall drives the creation of a proton gradient across the thylakoid membrane.
II. Diffusion of H+ (protons) across the membrane drives ATP synthesis.

Photosynthesis

I. In PS I (like PS II), transferred light energy excites P700, which loses an electron to an electron acceptor.
II. P700+ (P700 that is missing an electron) accepts an electron passed down from PS II via the electron transport chain.

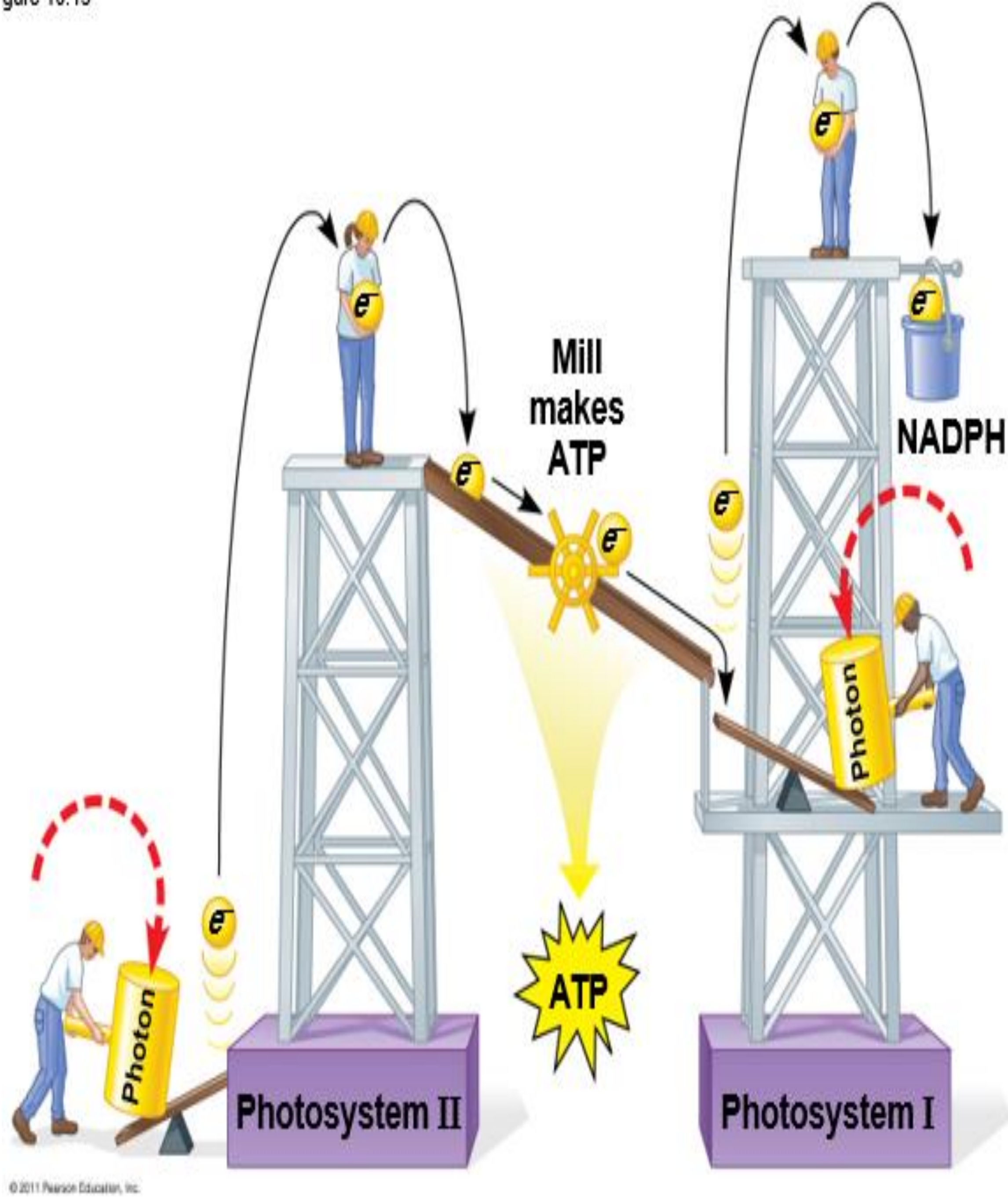


I. Each electron "falls" down an electron transport chain from the primary electron acceptor of PS I to the protein ferredoxin (Fd)
II. The electrons are then transferred to NADP+ and reduce it to NADPH
III. The electrons of NADPH are available for the reactions of the Calvin cycle
IV. This process also removes an H+ from the stroma

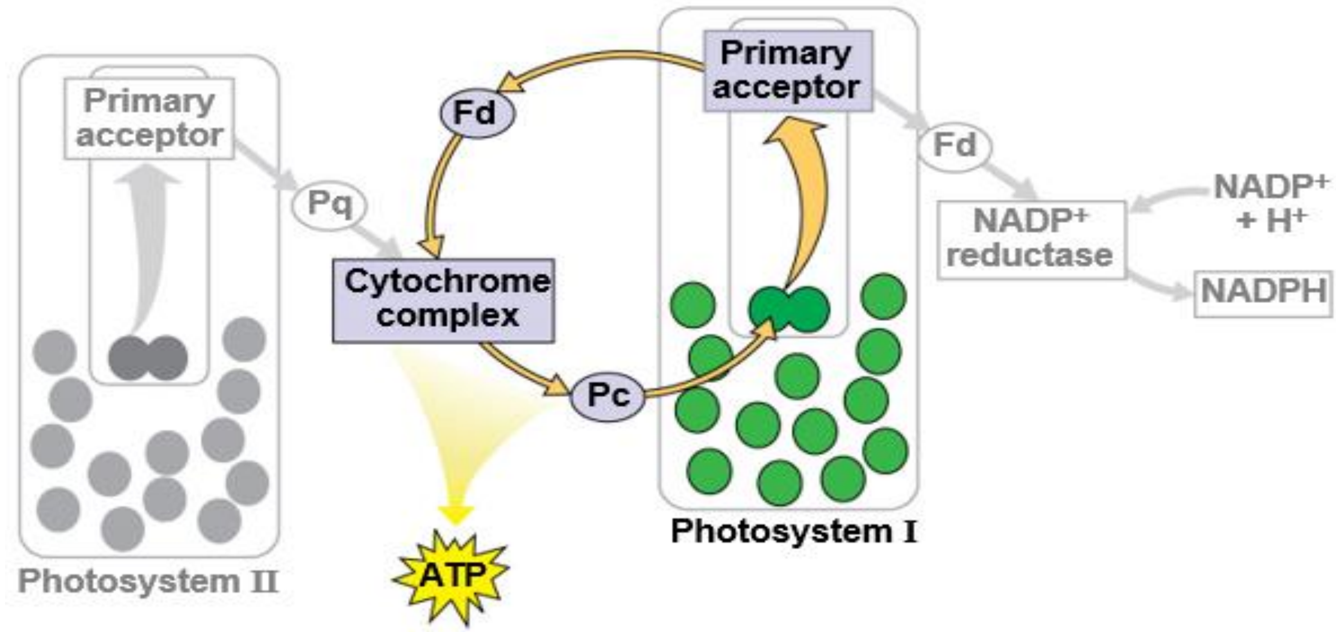


Photosynthesis

gure 10.15



6) Cyclic Electron Flow:
   a. Cyclic electron flow uses only photosystem I and produces ATP, but not NADPH.
   b. No oxygen is released.
   c. Cyclic electron flow generates surplus ATP, satisfying the higher demand in the Calvin cycle.

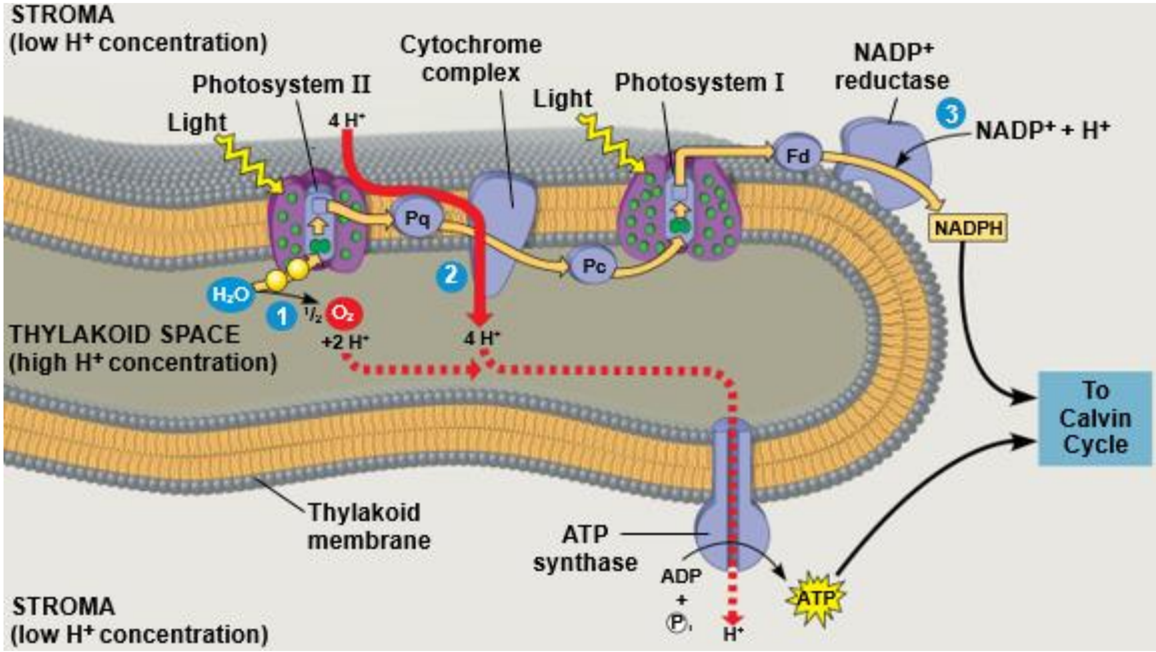


- Some organisms such as purple sulfur bacteria have PS I but not PS II.
- Cyclic electron flow is thought to have evolved before linear electron flow.
- Cyclic electron flow may protect cells from light-induced damage.

7) A Comparison of Chemiosmosis in Chloroplasts and Mitochondria:

- Chloroplasts and mitochondria generate ATP by chemiosmosis, but use different sources of energy
- Mitochondria transfer chemical energy from food to ATP; chloroplasts transform light energy into the chemical energy of ATP
- Spatial organization of chemiosmosis differs between chloroplasts and mitochondria but also shows similarities
- In mitochondria, protons are pumped to the intermembrane space and drive ATP synthesis as they diffuse back into the mitochondrial matrix
- In chloroplasts, protons are pumped into the thylakoid space and drive ATP synthesis as they diffuse back into the stroma

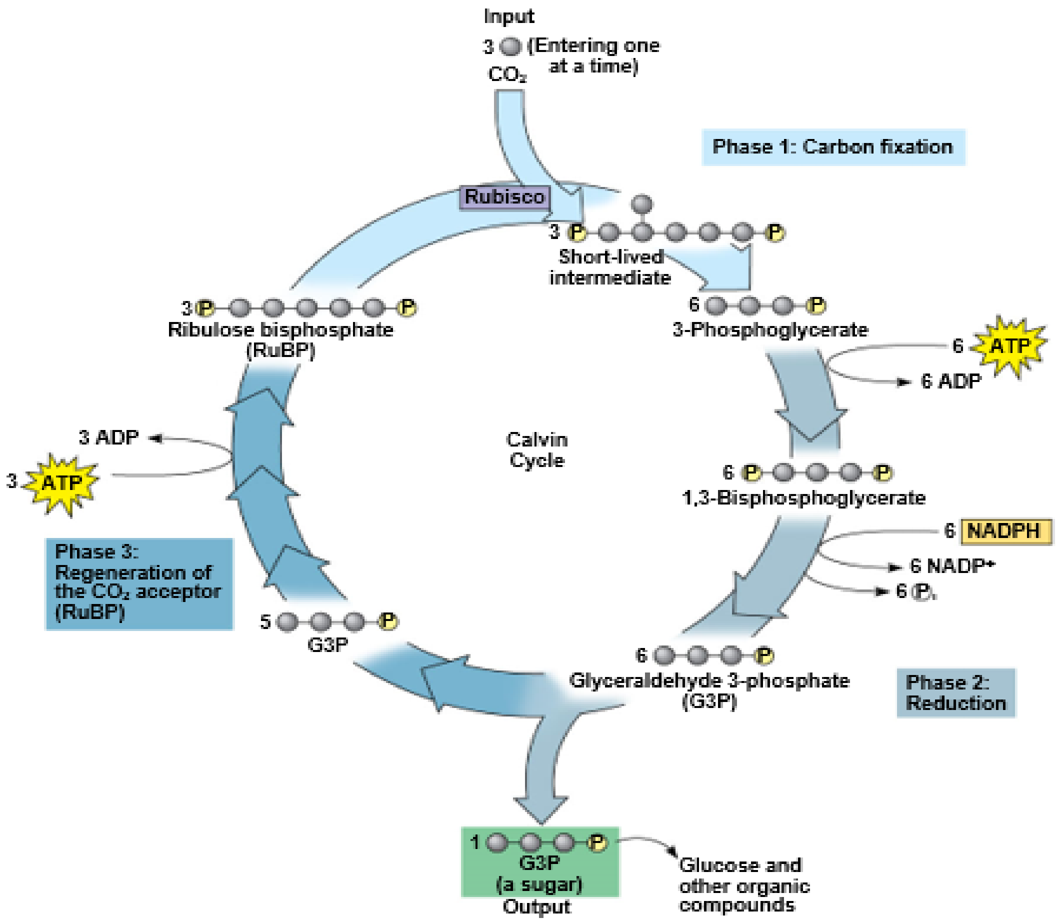
Photosynthesis



- ATP and NADPH are produced on the side facing the stroma, where the Calvin cycle takes place.
- In summary, light reactions generate ATP and increase the potential energy of electrons by moving them from H2O to NADPH.

Concept check will be included in the APPENDIX A

CONCEPT 10.3: The Calvin cycle uses the chemical energy of ATP and NADPH to reduce CO_2 to sugar



1. The Calvin cycle, like the citric acid cycle, regenerates its starting material after molecules enter and leave the cycle
2. The cycle builds sugar from smaller molecules by using ATP and the reducing power of electrons carried by NADPH
3. Carbon enters the cycle as CO2 and leaves as a sugar named glyceraldehyde 3-phospate (G3P)
4. For net synthesis of 1 G3P, the cycle must take place three times, fixing 3 molecules of CO2
5. The Calvin cycle has three phases
6. Carbon fixation (catalyzed by rubisco)
7. Reduction
8. Regeneration of the CO2 acceptor (RuBP)

Phases:

1. Phase1: carbon fixation:
   - The Calvin cycle incorporates each CO_2 molecule, one at a time, by attaching it to a five-carbon sugar named ribulose bisphosphate.
   - The enzyme that catalyzes this first step is RuBP carboxylase or rubisco.
   - The product: six-carbon intermediate so unstable that it immediately splits in half, forming two molecule of 3-phosphoglycerate. (for each CO_2 FIXED)
2. Phase 2: reduction
   - Each group of 3-phosphglycerate receives an additional phosphate group from ATP, becoming 1,3-biphosphoglycerate.
   - 1,3-biphosphoglycerate Loses a phosphate becoming G3P.
     The electrons from NADPH reduce a carboxyl group on 1,3-biphosphoglycerate to the aldehyde group of G3P, which store more potential energy.
   - We have 15 carbons → so we have 5 molecules of G3O and a one G3O that leaves the cycle (so the sum of all the carbons in and out of the cycle is 18 carbons).
3. Phase 3: regeneration of the CO_2 acceptor (RuBP)
   - In complex series of reactions, the carbon skeletons of five molecules of G3P are arranged by the last steps of the Calvin cycle in to three molecules of RuBP.
   - The cycle spends three more molecules of ATP.
   - The RuBP is now prepared to receive CO_2 again, and the cycle continuous.

Concept check will be included in A appendix.

Good luck ☺