Dr.Ahmad Al-Qawasmi

Biology

Chapter 11

photosynthetic processes

Med learn

❖ 11.1: Photosynthesis feed the biosphere

- Photosynthetic organisms (such as plants) have **chloroplasts** which capture light energy and convert it to chemical energy that is stored in sugar and other organic molecules → it is called photosynthesis

- **Modes in which organisms acquire energy:**

1) **Autotrophic nutrition** (self-feeders)

♦ They sustain themselves without eating anything derived from other living organisms

♦ They are the **producers** of the biosphere ➔ the ultimate sources of organic compounds for all non-autotrophic organisms by producing organic molecules from CO_2 & other inorganic molecules

♦ Almost all plants are **photoautotrophs** → using the energy of **sunlight** to make organic molecules

➢ Organisms that carry out photosynthesis: Plants, Algea, some unicellular eukaryotes, some prokaryotes (such as Cyanobacteria, purple sulfur bacteria) and certain other protists

2) **Heterotrophic nutrition** (other-feeding)

♦ Obtain their energy and food from organic materials **from other organisms**

♦ Heterotrophs are the biosphere's **consumers**

♦ **Decomposers:** they consume the remains of other organisms and organic litter (such as feces & fallen leaves) → **Examples:** most fungi and some prokaryotes

♦ Heterotrophs including humans, animals, fungi and many types of prokaryotes

❖ 11.2: [Photosynthesis converts light energy to the chemical energy of food]

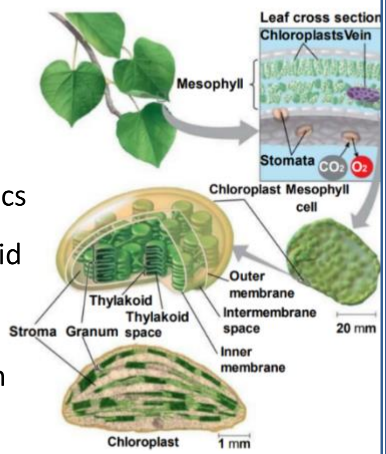
- The enzymes & molecules of photosynthesis are arranged (grouped) into **infolded regions** of biological membranes (plasma membrane of bacteria, internal membrane of chloroplast of eukaryotes)
- **Chloroplast:** The site of photosynthesis in eukaryotes such as plants, it was a photosynthetic prokaryote that lived inside an ancestor of eukaryotic cells **(endosymbiont theory)**

- All green parts of a plant have chloroplasts → **leaves** are the major sites of photosynthesis in plants

  ➢ **Mesophyll:** The interior tissue of the leaf, where chloroplasts are mainly found (each mesophyll cell contains 30-40 chloroplasts)

  ➢ **Stomata:** A microscopic **pores** in which carbon dioxide enters the leaf, and oxygen exits

  ➢ **Veins:** **Deliver** water that is absorbed by the roots to the leaves, also use veins to export sugar to roots and other non-photosynthetic parts of the plant



- Chloroplasts are surrounded by 2 membranes and have many parts:

  ➢ **Thylakoid:** It is a third membrane system, made up of sacs

♦ Thylakoid segregates the stroma from the thylakoid space inside these sacs

  ➢ **Stroma:** A dense **fluid** inside the chloroplast surrounding the thylakoid

  ➢ **Grana:** thylakoid sacs are **stacked in columns** (singular, granum)

- **Chlorophyll:** The green pigment that gives the leaves their color, it resides in the thylakoid membranes of the chloroplast

- Chlorophyll **absorbs the light energy** that drives the synthesis of organic molecules in the chloroplast
- The internal infolded photosynthetic membranes of some prokaryotes are also called **thylakoid membranes**

- In the presence of light, the green parts of plants produce organic compounds and oxygen from carbon dioxide and water. With this chemical equation:

$$6\ CO_2 + 12H_2O + \text{Light energy} \rightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$$

- Water appears on both sides of the equation because **12 molecules are consumed** and **6 molecules are newly formed** during photosynthesis → the net is 6 molecules consumed

$$6\ CO_2 + 6H_2O + \text{Light energy} \rightarrow C_6H_{12}O_6 + 6\ O_2$$

- Glucose is used to simplify the relationship between photosynthesis and respiration → but the direct product of photosynthesis is a three-carbon sugar that can be used to make glucose
- The simplest possible form of the equation (dividing by 6):

$$CO_2 + H_2O \rightarrow CH_2O + O_2$$

- CH_2O is not an actual sugar but represents the general formula for a carbohydrate
- The overall chemical change during photosynthesis is the reverse of cellular respiration
  - Both photosynthesis & cellular respiration occur in plant cells → having chloroplasts for photosynthesis & mitochondria for cellular respiration

- **O_2 given off** in photosynthesis is derived **from H_2O not from CO_2**
  - Before this discovery, the prevailing hypothesis was that photosynthesis split carbon dioxide ($CO_2 \rightarrow C + O_2$) and then added water to the carbon ($C + H_2O \rightarrow CH_2O$) meaning that the O_2 released during photosynthesis came from CO_2
  - Van Niel (a scientist) was investigating photosynthesis in bacteria that make their carbohydrate from CO_2 but do not release O_2. So, he concluded that CO_2 is not split into carbon and oxygen
  - Van Niel reasoned in one group of bacteria used hydrogen sulfide (H_2S) rather than water for photosynthesis, forming yellow globules of sulfur as a waste product that the bacteria split H_2S and used the hydrogen atoms to make sugar ($CO_2 + 2\ H_2S \rightarrow CH_2O + H_2O + 2\ S$)

- Generalized that idea, proposing that all photosynthetic organisms require a **hydrogen source** but that the source varies:

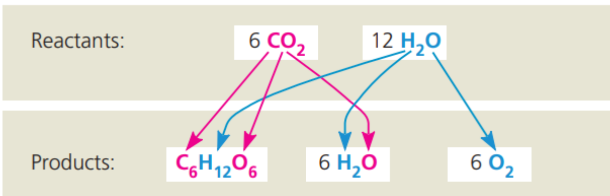
Plants: $CO_2 + 2\ H_2O \rightarrow [CH_2O] + H_2O + O_2$

Sulfur bacteria: $CO_2 + 2\ H_2S \rightarrow [CH_2O] + H_2O + 2\ S$

General: $CO_2 + 2\ H_2X \rightarrow [CH_2O] + H_2O + 2\ X$

- Scientists confirmed van Niel's hypothesis by **using oxygen-18 (^{18}O a heavy isotope)** as a **tracer to** follow the path of oxygen atoms during photosynthesis. The experiments showed:
  - Experiment 1 → The O atom from water molecule was labeled with ^{18}O
  - Experiment 2 → The O atom from carbon dioxide was labeled with ^{18}O
  - The result: **O_2** is released from plants (was labeled with ^{18}O) → only if **water was the source** of the tracer and If the ^{18}O was introduced to the plant in the form of CO_2, the label did not turn up in the released O_2

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

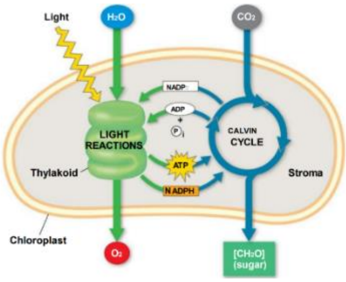


- Photosynthesis and cellular respiration → <u>Both processes involve redox reactions</u>
  - Photosynthesis **reverses** the direction of electron flow compared to respiration
  - Photosynthesis is a **redox process** in which: [**H_2O** is **oxidized** and **CO_2** is **reduced** to sugar]
  - It is **<u>endergonic</u>** process (requires energy) this energy boost that occurs during photosynthesis is provided **by light**

becomes reduced

$$\text{Energy} + 6\,CO_2 + 6\,H_2O \longrightarrow C_6H_{12}O_6 + 6\,O_2$$

becomes oxidized



- Photosynthesis consist of 2 stages are:
  1. **The light reactions (**the <u>photo part</u> of photosynthesis**)**
  2. **Calvin cycle (**the <u>synthesis part</u> of photosynthesis**)**
     - ➢ The chloroplast uses light energy to make sugar by coordinating the two stages of photosynthesis

- The light reactions in the **<u>thylakoids membrane</u>** are the steps of photosynthesis that **convert solar energy to chemical energy**
- The light reactions include:
  - Split **H_2O** providing a **source of electrons & protons** (H^+) and giving off **O_2** as a by-product
  - Reduce the electron acceptor **$NADP^+$ to NADPH (**by adding 2 electrons and 1 H^+**)**
    - ➢ light absorbed by chlorophyll drives a transfer of the electrons and hydrogen ions from water to $NADP^+$, where they are temporarily stored. In which $NADP^+$ is reduced to NADPH
  - **Generate ATP** from ADP by adding a phosphate group using chemiosmosis
    - ➢ Chemiosmosis powers the addition of a phosphate group to ADP in a process called **photophosphorylation**

- **$NADP^+$** (nicotinamide adenine dinucleotide phosphate): an electron acceptor similar to NAD^+
  - ➢ The difference between them is only by the presence of an <u>extra phosphate</u> group in the $NADP^+$
- Light reactions convert light (solar) energy into <u>chemical energy stored in ATP & NADPH</u>
- Light reactions produce <u>no sugar</u>

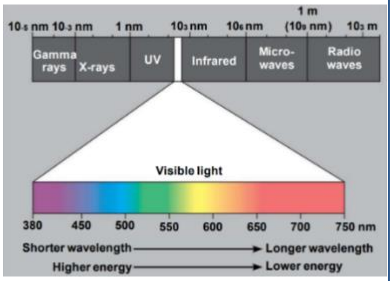
- Calvin cycle **produce sugar** → only in the presence of the NADPH & ATP produced by the light reactions
  - ➢ The metabolic steps of the Calvin cycle are sometimes referred to as the <u>dark reactions</u>, or <u>light-independent reactions</u>, because none of the steps requires light directly
  - ➢ The Calvin cycle in most plants occurs **during daylight** ➔ because light reactions provide the NADPH and ATP that the Calvin cycle requires

- The **light reactions** occur in the **thylakoid membrane**
- **Calvin cycle** occurs in the **stroma**

❖ 11.3: [The light reactions convert solar energy to the chemical energy of ATP and NADPH]

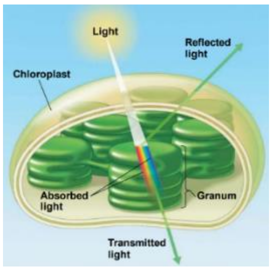
- Chloroplasts are chemical factories powered by the sun
- Light is a form of electromagnetic energy **(electromagnetic radiation)** → It travels in **rhythmic waves**
- Electromagnetic waves are <u>disturbances of electric and magnetic fields</u> rather than disturbances of a material medium such as water
  - ➢ **Wavelength:** is the **distance** between crests of electromagnetic waves

- Wavelengths range from less than a nanometer (gamma rays) to more than a kilometer (radio waves)
- **Electromagnetic spectrum:** It is the entire range of electromagnetic energy radiation
- **Visible light:** It is the light that produce colors that we **can see,** it has a narrow range of wavelengths from **380 nm to 750 nm** → it includes light with that **drive photosynthesis**



- Light consists of discrete particles, called **photons**
  - ➢ The amount of energy of each photon is **inversely** related to the wavelength of the light (high energy = short wavelength)
  - ➢ The photon of violet light has energy more than twice the energy of red light photon
- The sun radiates the full spectrum of electromagnetic energy → but the atmosphere acts like a selective window allowing visible light to pass through while screening out a substantial fraction of other radiation

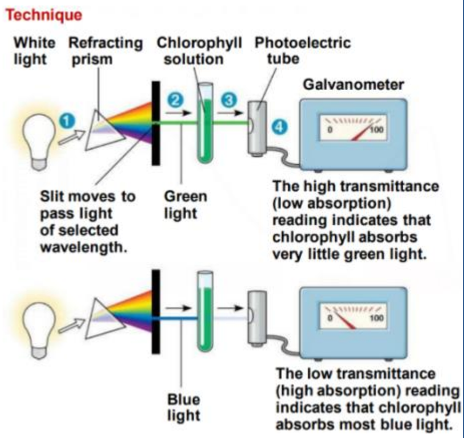
- When light meets matter, it may be reflected, transmitted, or absorbed
- **Pigments:** substances that absorb visible light
  - ➢ Different pigments absorb different wavelengths
  - ➢ Wavelengths that are **not absorbed** are **reflected or transmitted** → so we can see this color
  - ➢ Wavelengths that are **absorbed disappear** (appear black)



- Leaves appear green because chlorophyll absorbs violet-blue and red light while reflects and transmits green light ➔ that indicates that the **violet-blue and red light work best** for photosynthesis, since they are absorbed, while **green is the least effective color**

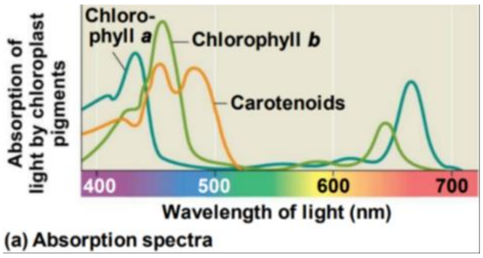
- **Spectrophotometer:** An instrument that **measures a pigment's ability to absorb** various wavelengths by sending light through pigments and measures the fraction of light transmitted at each wavelength

- **Absorption spectrum:** A **graph** that plots a pigment's light absorption versus wavelength:
  1) White light is separated into colors (wavelengths) by a prism
  2) Each color of the light is passed through the sample
  3) The transmitted light strikes a photoelectric tube, which converts the light energy to electricity current which is measured by a galvanometer
  4) The meter indicates the fraction of light transmitted through the sample, from which we can determine the amount of light absorbed

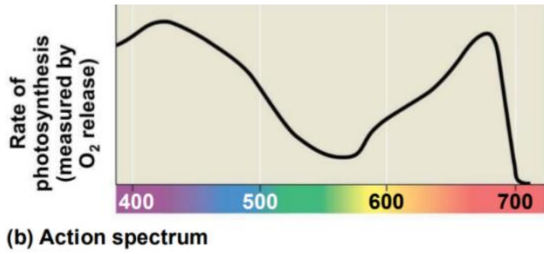


- There are three types of pigments in chloroplasts:
  - o **Chlorophyll a:** is the key **light-capturing pigment** that participates directly in the light reactions
  - o **Chlorophyll b:** the **accessory** pigment
  - o **Carotenoids:** a group of **accessory** pigments

- **Action spectrum:** A graph that profiles the relative **effectiveness** of different wavelengths of radiation in **driving a process**
- An action spectrum is prepared by illuminating chloroplasts with light of different colors and then plotting wavelength against some measurements of photosynthetic rate such as CO_2 consumption or O_2 release (so if the wavelength of the light is favorable for photosynthesis, O_2 is released)

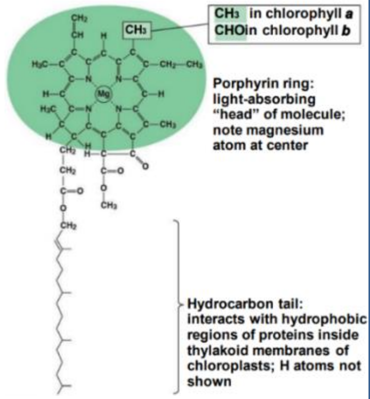


(a) Absorption spectra



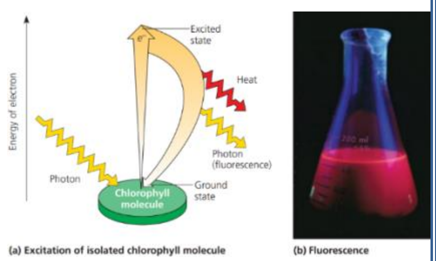
(b) Action spectrum

- The action spectrum for photosynthesis is <u>much broader</u> than the absorption spectrum of (chlorophyll *a*) → so, it <u>underestimates</u> the effectiveness of certain wavelengths in driving photosynthesis
  - Because <u>**accessory pigments**</u> with different absorption spectra also present in chloroplasts broaden the spectrum of colors that can be used for photosynthesis



- The **difference** between the structure of chlorophyll *a* & *b* is only in 1 of the functional groups bonded to the porphyrin ring (CH_3 in chlorophyll ***a***, CHO in chlorophyll ***b***)
- Why does chlorophyll <u>*a* appear blue green</u> and chlorophyll <u>*b* olive green</u> under visible light:
  - Due to the slight <u>**structural difference**</u> between them → so they <u>**absorb at slightly different wavelengths**</u> in the red and blue parts of the spectrum
- Cyanobacterium has 2 other types of chlorophyll ➔ chlorophyll *f* & *d*
- Carotenoids are various shades of **yellow & orange** because they absorb violet and blue-green light
  - They **broaden the action spectrum**
  - They also act in **photoprotection** by absorbing & dissipating excessive light energy (which can damage chlorophyll or interact with oxygen)
    - ✓ **Carrots** are rich in carotenoids → which have a photoprotective role in the human eye

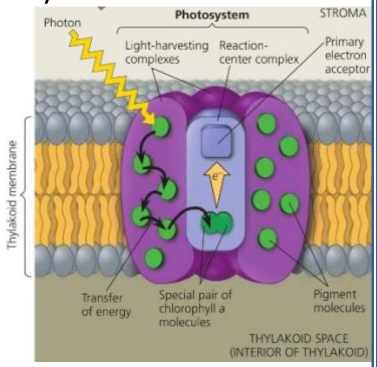
- When a pigment absorbs light, the <u>colors</u> corresponding to the absorbed wavelengths <u>disappear</u> from the spectrum of the transmitted and reflected light, but <u>energy cannot disappear</u>
- When a molecule absorbs a photon of light → an electron is elevated from its normal orbital to an orbital where it has <u>more</u> potential energy (**excited state, unstable**)
  - When the electron is in its normal orbital it is called **ground state**
- The only photons absorbed are those with **energy** exactly <u>equal</u> to the **energy difference** between the ground & excited states
- In an isolated pigment:
  - The electron in the excited state can not stay excited for a long time because it is a high-energy state and unstable, so the excited electrons <u>drop back down</u> to the ground-state orbital in a billionth of a second → **releasing their excess energy as heat**
  - When excited electrons fall back to the ground state → photons are given off (**afterglow**) called **fluorescence**
- If an isolated solution of chlorophyll is excited with ultraviolet light, it will fluoresce with a red-orange glow



(a) Excitation of isolated chlorophyll molecule (b) Fluorescence

- To conclude:
  - If an isolated pigment is illuminated → it will give off <u>**heat & fluorescence**</u>

- **Photosystems:** complexes of proteins, chlorophyll & organic molecules in the thylakoid membrane
- They consist of:
    - **Reaction-center complex:** An organized association of proteins holding a special pair of **chlorophyll *a*** molecules and a **primary electron acceptor**
    - **Light-harvesting complexes: Pigment molecules bound to proteins** surround the reaction-center complexes → they transfer the energy of photons to the reaction center



- Each light-harvesting complex has <u>various</u> pigment molecules (which may include chlorophyll *a*, chlorophyll *b*, and carotenoids)

- ## <u>How does it work??</u>
- When a pigment molecule absorbs a photon, the **energy is transferred** from pigment molecule to pigment molecule within a light-harvesting complex, until it is passed to the pair of chlorophyll a molecules in the reaction-center complex
- The pair of chlorophyll *a* molecules in the reaction-center complex are special because they can transfer their electrons to a different molecules (primary electron acceptor)
- So, as the chlorophyll electron is excited to a higher energy level, the primary electron acceptor **captures this electrons (a redox reaction)**
- The result ➔ solar-powered transfer of an electron from a chlorophyll a molecule to the primary electron acceptor

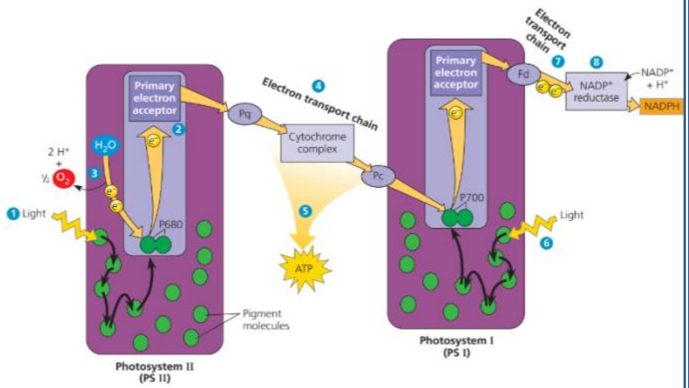
- There are two types of photosystems in the thylakoid membrane:
    1) **Photosystem II (PS II):** its reaction-center chlorophyll ***a*** is **P680** (because this pigment <u>is best at absorbing light having a wavelength of 680 nm</u> in the red part of the spectrum)
    2) **Photosystem I (PS I):** Its reaction-center chlorophyll ***a*** is **P700** (because it <u>most effectively absorbs light of wavelength 700 nm</u> in the far-red part of the spectrum)

- P680 and P700 are nearly identical chlorophyll *a* molecules ➔ But, their association with **different proteins** in the thylakoid membrane affects the electron distribution in the two pigments and accounts for the <u>slight differences in their light-absorbing properties</u>

- The 2 photosystems work together to produce ATP and NADPH

❖ Linear Electron Flow

- Linear electron flow involves the <u>flow of electrons</u> through the photosystems and other molecules embedded in the thylakoid membrane to produce ATP and NADPH using light energy



- ## <u>The steps:</u>
    - A photon hits a pigment in a light-harvesting complex of <u>**PS II**</u> and its energy is passed by boosting one of its electrons to a higher energy level → the electron falls back to its ground state <u>**exciting**</u> an electron in a nearby pigment molecule → the process continues until it exciting the P680 pair
    - Primary electron acceptor <u>**captures**</u> the excited electron from P680 (it becomes <u>**P680⁺**</u>)
        - P680+ is the **strongest oxidizing agent** known → so it must gain electrons returning P680

- An enzyme catalyze the splitting of H_2O is split into:
  - ✓ **Electrons** which are supplied one by one to the $P680^+$ pair (replacing the transferred electron)
  - ✓ **H^+** are released into the thylakoid space
  - ✓ **Oxygen atom** combines with other oxygen atom forming O_2 that is released as a by-product

- Each photo-excited electron passes from the primary electron acceptor of PS II to PS I via an electron transport chain

- Each component of **electron transport chain carries out redox reactions** as electrons flow down the chain → releasing free energy that is used to pump protons (H^+) into the thylakoid space, contributing to a proton gradient across the thylakoid membrane → The potential energy stored in the proton gradient is used to make ATP **(chemiosmosis)**

- **Electron transport chain** between PS II and PS I (similar to the chain that is present in cellular respiration) is made up of:
  - **Plastoquinone (Pq)**
  - **Cytochrome complex**
  - **A protein called plastocyanin (Pc)**

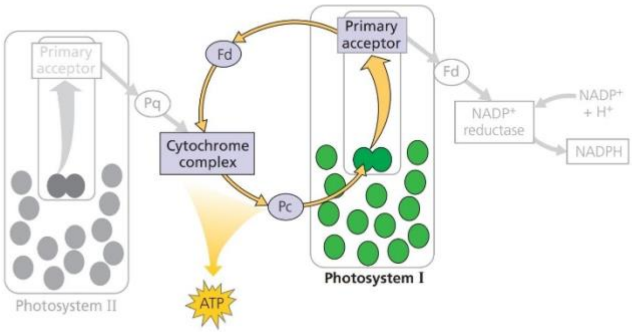
- In **PS I** (like PS II), transferred light energy excites P700, causing it to **lose an electron** to an electron acceptor (it becomes $P700^+$ which act as electron acceptor)
  - $P700^+$ **accepts an electron** passed down from PS II via the electron transport chain

- **Photoexcited** electrons fall down a second electron transport chain from the primary electron acceptor of PS I to the protein **ferredoxin (Fd)**
  - This chain does not create a proton gradient and thus does **not produce ATP**

- **$NADP^+$ reductase** transfer the electrons to $NADP^+$ → reducing it to NADPH
  - This process also removes an H^+ from the stroma

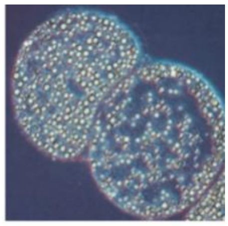
- The light reactions use solar power to generate **ATP** (provide **chemical energy**) and **NADPH (reducing power)** used to the carbohydrate-synthesizing reactions of the Calvin cycle

❖ Cyclic Electron Flow



- **Cyclic flow:** It is a short circuit in which the electrons cycle back from ferredoxin (Fd) to the cytochrome complex then via a plasto-cyanin molecule (Pc) → to a P700 chlorophyll in the PS I reaction-center complex
  - It uses photosystem I but **not** photosystem II
  - **Ferredoxin (Fd) → Cytochrome colplyx → Plasto-cyanin → P700**
  - There is **no production of NADPH** and **no release of oxygen** but it **generates ATP**

- The **purple sulfur bacteria** and the **green sulfur bacteria** → are species of photosynthetic bacteria which have a **single photosystem** related to either PS II or I
  - So, in these bacteria cyclic electron flow is the one and only means of generating ATP during the process of photosynthesis



Purple sulfur bacteria

- Cyclic electron flow can also occur in photosynthetic species that possess **both photosystems**, this includes:
  - Some prokaryotes, such as the **cyanobacteria**
  - Photosynthetic eukaryotes (such as plant) having mutations

Cyanobacteria

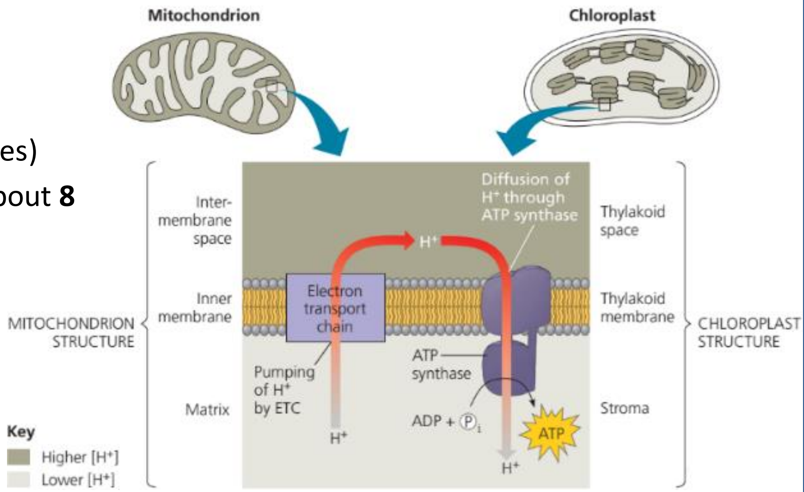
- Cyclic electron flow may be **photo-protective**

❖ A Comparison of Chemiosmosis in Chloroplasts and Mitochondria

- Chloroplasts and mitochondria generate ATP by the same basic mechanism (chemiosmosis) but use different sources of energy
  - ➢ An electron transport chain **pumps protons (H^+)** across a membrane as electrons are passed through a series of carriers that are progressively more electronegative
  - ➢ Electron transport chains transform redox **energy to a proton-motive force** → which represents a potential energy stored in the form of **H^+ gradient across a membrane**
  - ➢ An **ATP synthase** complex in the same membrane couples the **diffusion of hydrogen** ions down their gradient to the phosphorylation of ADP, forming ATP

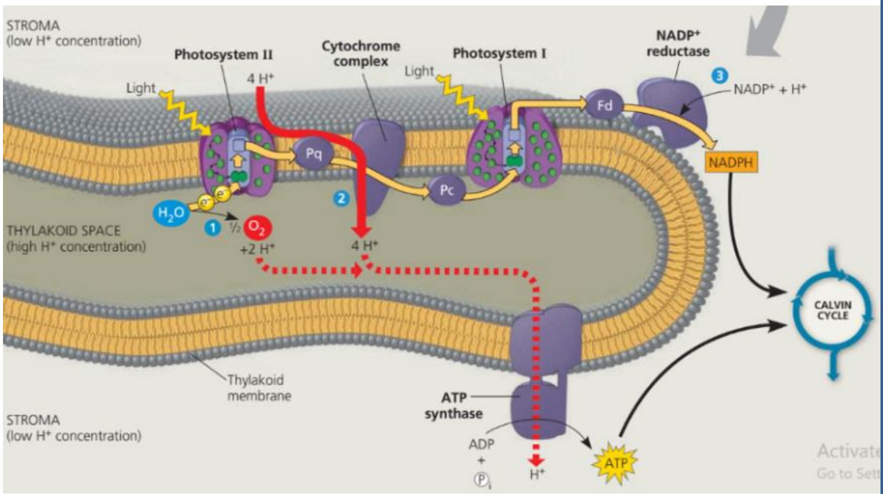
	Oxidative Phosphorylation (mitochondria)	Photophosphorylation (Chloroplast)
The source of e^-	Organic molecules (Fuel, Food)	Water
Energy transformation	Chemical (food) → Chemical (ATP)	Light → Chemical (ATP)
The location of ETC and ATP synthase	Inner mitochondrial membrane	Thylakoid membrane
The direction of pumping H^+	From Matrix → intermembrane space	From Stroma → Thylakoid space

- When chloroplasts are illuminated:
  - ➢ The pH in the **thylakoid space** drops to about **5** (H^+ concentration increases)
  - ➢ The pH in the **stroma** increases to about **8** (H^+ concentration decreases)
  - ➢ This gradient of three pH units corresponds to a **thousand fold** difference in H^+ concentration
  - ➢ If the lights are then turned off the pH gradient is abolished



- The light reactions of photosynthesis **generate ATP** and increase the potential energy of electrons by moving them from H_2O to **NADPH**

- ATP and NADPH are produced on the side of the thylakoid membrane facing the stroma, where the Calvin cycle takes place which uses ATP and NADPH to power the synthesis of sugar from CO_2



❖ 11.3: [The Calvin cycle uses the chemical energy of ATP and NADPH to reduce CO2 to sugar]

- The Calvin cycle, like in citric acid cycle → it regenerates its starting material
- But unlike the citric acid cycle, the Calvin cycle is **anabolic**, building carbohydrates from smaller molecules and consuming energy
- It builds sugar from smaller molecules by using **ATP** and the reducing power of electrons in **NADPH**
- The carbohydrate produced directly from the Calvin cycle is **not glucose** → It is a three-carbon sugar called **Glyceraldehyde 3-Phosphate (G3P)**
  - ➢ For net synthesis of one G3P, the cycle must take place three times, fixing three molecules of CO_2 one per turn of the cycle

- **The Calvin cycle has three phases:**

1. Carbon fixation

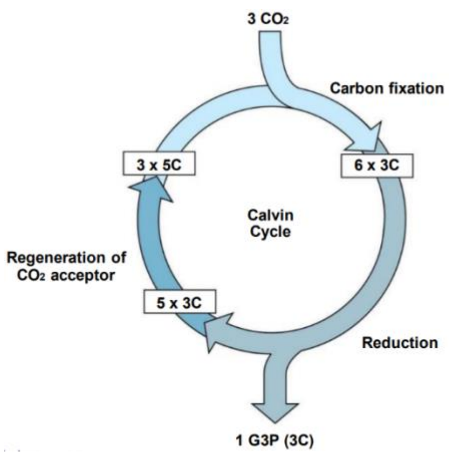
- The incorporation of each $\mathbf{CO_2}$ molecule into **ribulose bisphosphate (RuBP)** using the enzyme **rubisco**
  - ➢ **Rubisco** = Ribulose BISphosphate Carboxylase-Oxygenase**,** it is the most abundant protein in the chloroplasts and is also thought to be the most abundant protein on Earth
- For each CO_2 fixed the product is → **six-carbon intermediate**
  - ➢ It is short-lived because it is so energetically **unstable** → So, it immediately splits in half forming 2 molecules of **3-phosphoglycerate**

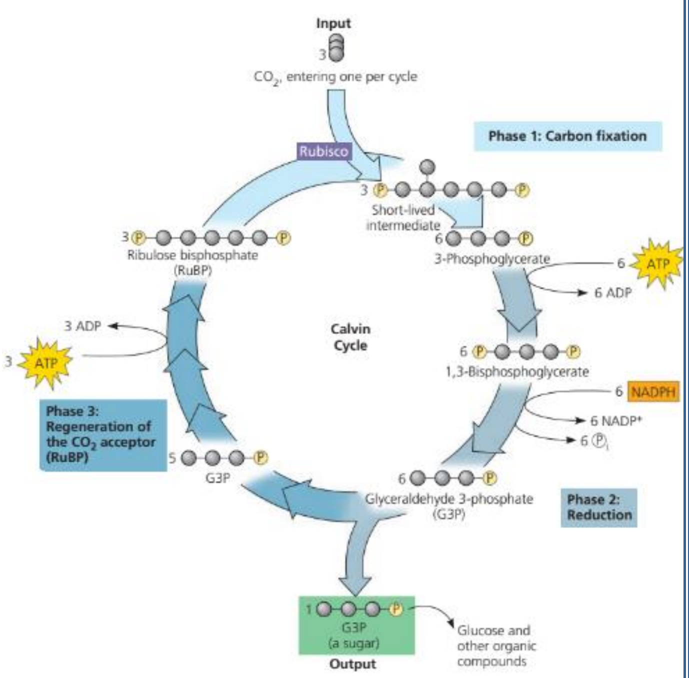
2. Reduction

- Each molecule of 3-phosphoglycerate receives an additional phosphate group from ATP, becoming **1,3-bisphosphoglycerate**
- The electrons from **NADPH** reduce a *carboyxl* group on **1,3-bisphosphoglycerate** to the *aldehyde* group of **G3P**, which stores more potential energy
  - ➢ **1,3-bisphosphoglycerate → G3P (**Carboxyl → aldehyde + a phosphate group is removed**)**
- (3 cycle → 1 G3P molecules) ➔ as a net we began with 15 carbons (3 RuBP) and finished with 18 carbons (6 G3P) ➔ That requires 3 CO_2 + 6 ATP + 6 NADPH
  - ➢ 1 G3P is released and the remaining 5 G3P are used to regenerate RuBP

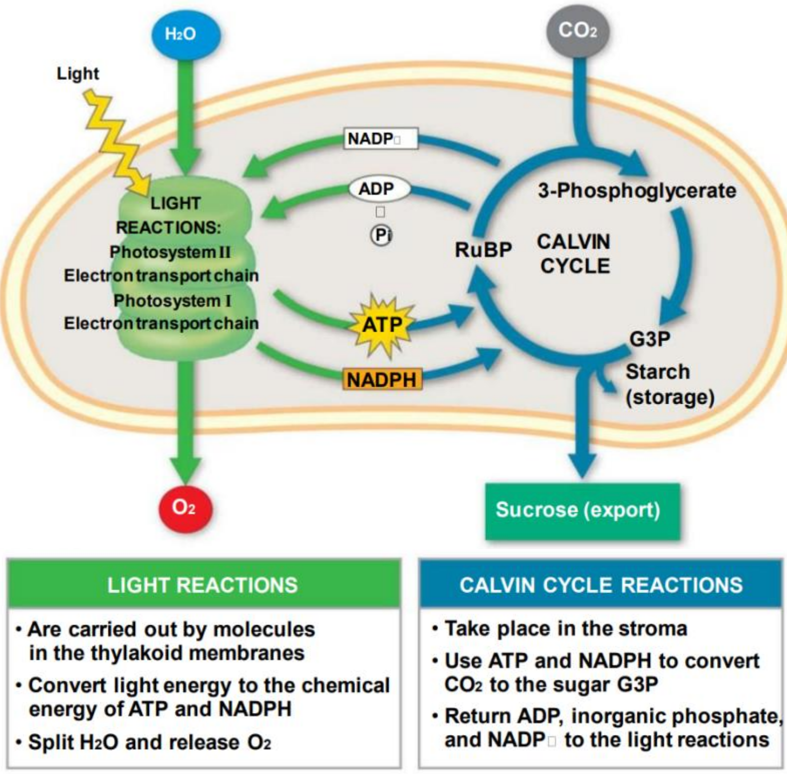
3. Regeneration of the CO_2 acceptor

- The rearrangement of the 5 remaining molecules of G3P to regenerate the initial CO_2 receptor, RuBP
  - ➢ 3 ATP are required to power this step





- For the net synthesis of **one G3P** molecule, the Calvin cycle consumes a total of: **9 ATP + 6 NADPH**
- The G3P that is produced from the Calvin cycle becomes the starting material for metabolic pathways that synthesize other organic compounds, including glucose (from two molecules of G3P) and other carbohydrates



Follow me

DRAMQ02

Past Papers

1. **The part of chlorophyll molecule which absorbs light is:**
   A. Porphyrin ring
   B. Hydrocarbon tail
   C. Mg atom
   D. A and B
   E. None of the above

   Answer: A

2. **Organisms capable of carrying out photosynthesis are described as:**
   A. Phototroph
   B. Heterotroph
   C. Chemotrophic
   D. Decomposer
   E. Parasitic

   Answer: A

3. **The correct sequential flow of electrons from PSI to PSII is:**
   A. PSII – Pq – Cytochrome – Pc – PSI
   B. Pq – PSII – Cytochrome – PSI – Pc
   C. Pc – PSII – Cytochrome – PSI – Pq
   D. PSI – Pq – Cytochrome – Pc – PSII
   E. PSI – Pc – Cytochrome – Pq – PSII

   Answer: A

4. **Which of the following is the ultimate source of the carbon in the sugar produced during Calvin cycle?**
   A. CO_2
   B. Water
   C. ATP
   D. NADPH
   E. all of the above

   Answer: A

5. **Which of the following does not occur during the Calvin cycle?**
   A. Carbon fixation
   B. oxidation of NADPH
   C. release of oxygen
   D. regeneration of the CO_2 acceptor
   E. consumption of ATP

   Answer: C

6. **Which of the following is/are used in the reduction phase of the Calvin cycle?**
   A. CO_2
   B. RuBP
   C. ATP
   D. NADPH
   E. ATP and NADPH

   Answer: E

7. What catalyses the carbon fixation phase of the Calvin cycle?

A. P700
B. Kinase
C. Rubisco
D. ATP synthase
E. Regenerase

Answer: C

8. The CO_2 acceptor in Calvin cycle is:

A. RuBP
B. Rubisco
C. Oxaloacetate
D. Carbon monoxide
E. None of the above

Answer: A

9. In the cyclic electron flow during photosystem:

A. No NADPH is produced
B. No O_2 is produced
C. Only ATP is produced
D. Both NADPH and ATP are produced
E. A, B and C are correct

Answer: E

10. If thylakoid membrane became leaky to H^+, which of the following processes will affected most?

A. Absorption of photons
B. Linear electron flow
C. Cyclic electron flow
D. The synthesis of ATP
E. Splitting of water molecules

Answer: D

11. The electrons lost from the reaction center pigment of PS II are replaced by electrons from:

A. ATP
B. CO_2
C. H_2O
D. NADPH
E. P700

Answer: C

12. In photosynthesis in plants, the transfer of electrons through electron transport chain provides energy to:

A. Pump protons across intermembrane space
B. Pump protons across thylakoid membrane
C. Pump protons into the stroma
D. Pump protons into the matrix
E. None of the above

Answer: B

13. When water splits in the process of photosynthesis, what it does supply to oxidize P680:

A. Electrons
B. Hydrogen ion
C. Carbon dioxide
D. Oxygen
E. ATP

Answer: A

14. Synthesis of one molecule of G3P needs:

A. 9 NADPH molecules
B. 9 NADPH and 6 ATP
C. 6 NADPH and 9 ATP
D. Fixation of 3 CO2 molecules, 6 NADPH, 9 ATP
E. Fixation of 3 CO2 molecules, 9 NADPH, 6 ATP

Answer: D

15. Which of the following is the BEST lights used for photosynthesis?

A. Green and red
B. Red and violet - blue
C. Green and violet blue
D. Red and yellow
E. Orange and yellow

Answer: B

16. In the light reactions in photosynthesis, the final acceptor of both electrons and protons is:

A. NAD^+
B. $NADP^+$
C. The primary electron acceptor
D. B and C
E. Either A or B

Answer: B

17. What are the products of linear photophosphorylation?

A. Heat and fluorescence
B. ATP and P700
C. ATP and NADPH
D. ADP and NADP
E. P700 and P680

Answer: C

18. In photosynthesis, the chemiosmosis production of ATP:

A. Is done by Calvin cycle
B. Require the input of NADPH
C. Is typically similar to ATP production of ATP in mitochondria
D. A and B
E. None of the above

Answer: C

19. An overall result of photosynthesis in plants is the use of electrons from water to reduce:

A. Glucose

B. Carbon dioxide

C. Oxygen

D. Chlorophyll

E. NADPH

Answer: B

20. In mechanism, photophosphorylation is most similar to

A. Substrate - level phosphorylation in glycolysis

B. Oxidative phosphorylation in cellular respiration

C. The Calvin cycle

D. Carbon fixation

E. Reduction of NADP

Answer: B

21. Generation of proton gradients across membranes occurs during:

A. Photosynthesis

B. Respiration

C. Both photosynthesis and respiration

D. Neither photosynthesis nor respiration

E. Photorespiration

Answer: C

22. The letter X represents

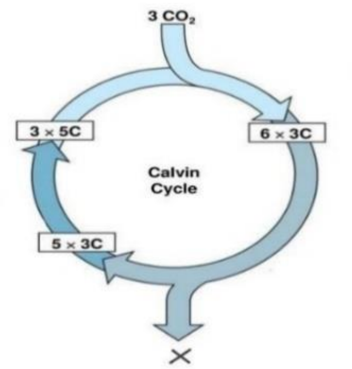
A. G3P

B. RuBP

C. glucose

D. Oxaloacetate

E. None of the above



Answer: A

23. Where does the Calvin cycle take place?

A. Stroma of the chloroplast

B. Thylakoid membrane

C. Cytoplasm surrounding the chloroplast

D. Chlorophyll molecule

E. Outer membrane of the chloroplast

Answer: A