

Light & Plants

Photosynthesis

Photo = Light

Synthesis = To Join

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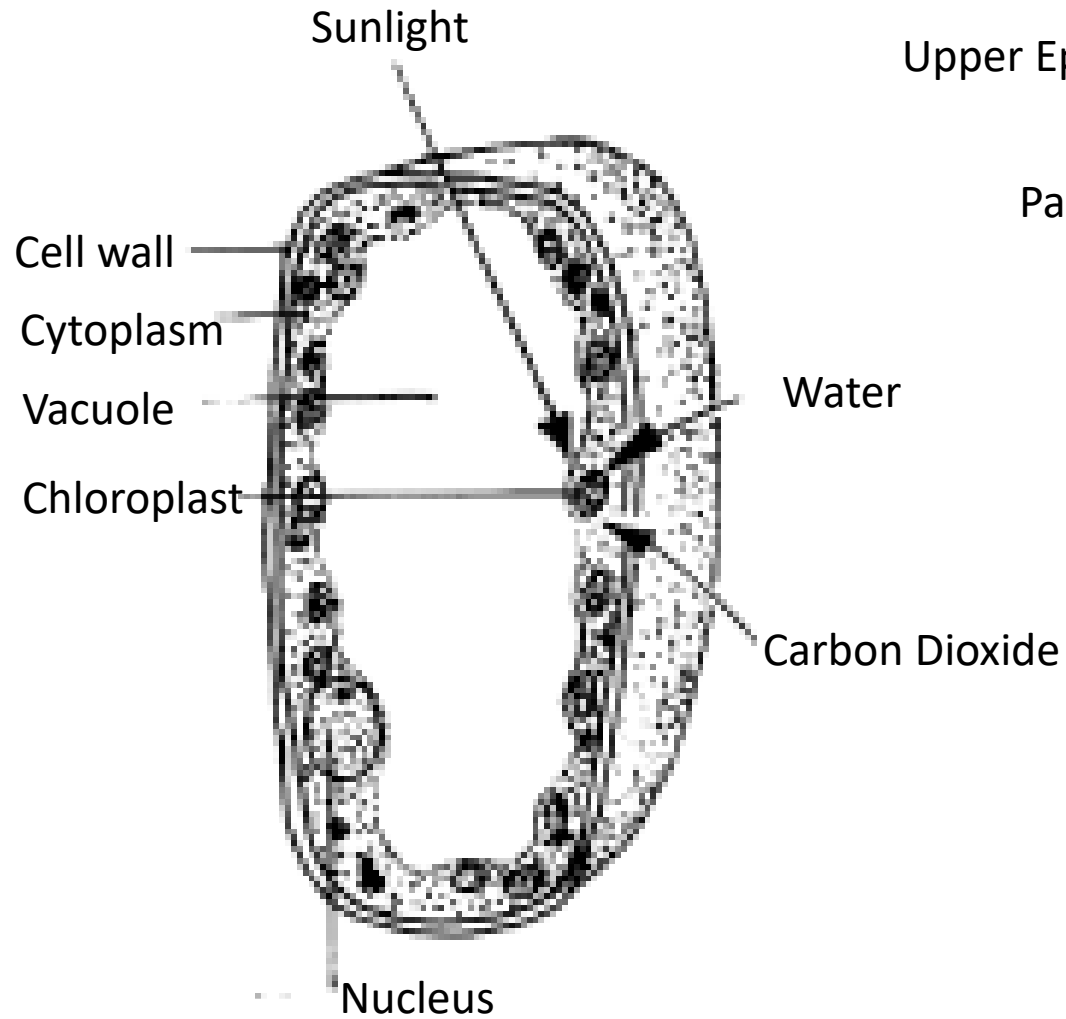
What is Photosynthesis?

- Process by which green plants, in the presence of light combine water and carbon dioxide to form carbohydrates
- Oxygen is released as a byproduct
- Current knowledge of photosynthesis has resulted from discoveries made over 300 years of work
- Photosynthesis is represented by the overall chemical equation:
 - $6\text{CO}_2 + 12\text{H}_2\text{O} \xrightarrow{\text{Chlorophyll \& Sunlight}} \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{H}_2\text{O} + 6\text{O}_2$
 - Carbon Dioxide and water converted to carbohydrate (glucose) and oxygen
 - O_2 released comes from water and not CO_2

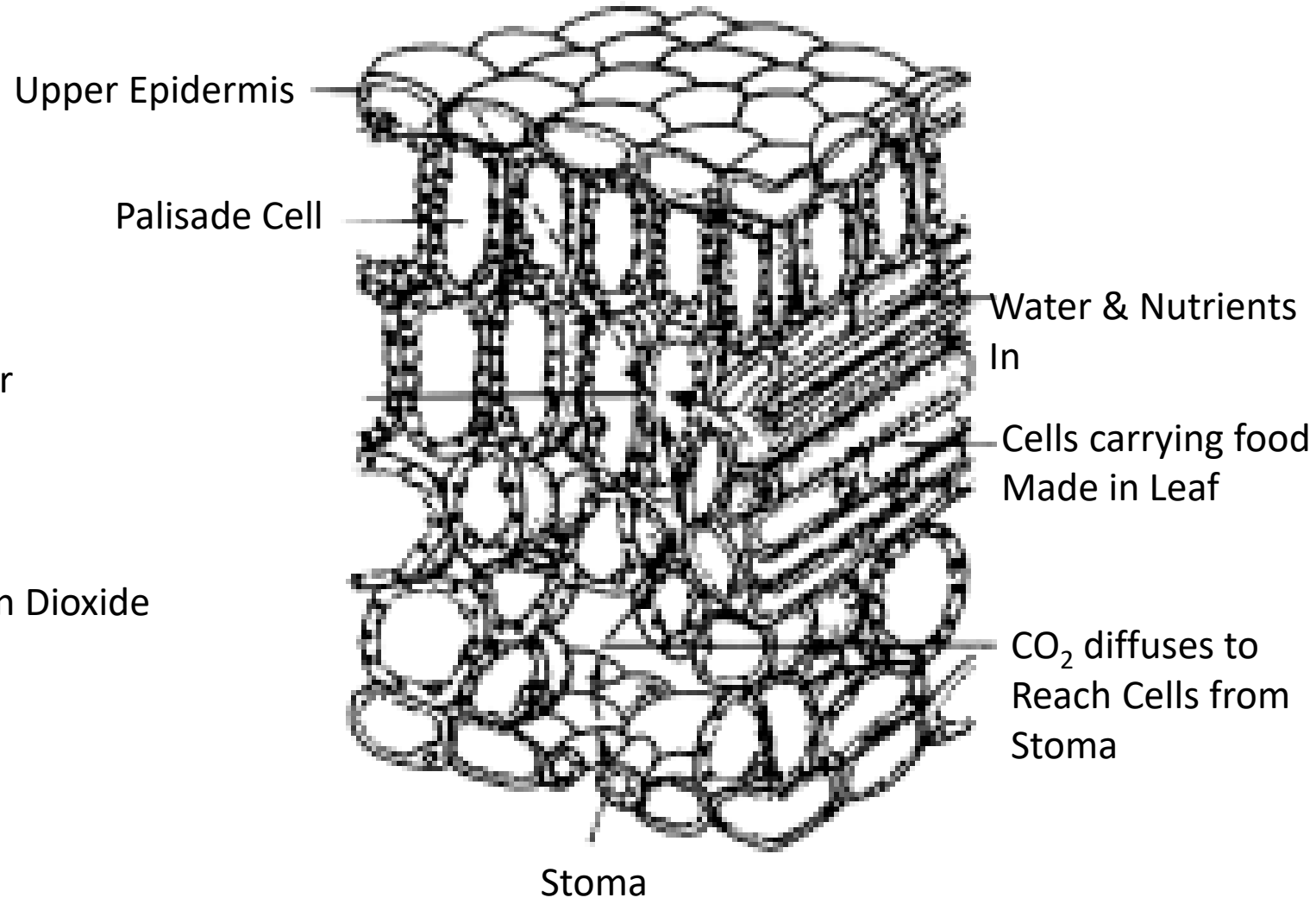
Significance

1. Green plants possess the green pigment, chlorophyll which can capture, transform, translocate and store energy which is readily available for all forms of life on this planet.
2. Except green plants, no other organism can directly utilize solar energy to synthesize food, hence they are dependent on green plants for their survival.
3. During photosynthesis, oxygen liberated into the atmosphere makes the environment livable for all aerobic organisms.
4. Plants and plant products are the major food sources of almost all organisms on the earth.
5. Fossil fuels like coal, gas, and oil represent the photosynthetic products of the plants belonging to early geological periods.

Cell and Leaf Structure for Photosynthesis



Cell Cross Section



Leaf Cross Section

Photosynthetic Pigments

- Chloroplast thylakoid membranes contain pigments that absorb light of different wavelengths and carry out the photochemical reactions of photosynthesis
 - Higher plant pigments are chlorophyll and carotenoids
- Chlorophyll (-a, -b) is principle pigment, a large molecule that absorbs light largely in the blue and red regions (why leaves look green)
 1. Chlorophyll-a is the primary photosynthetic pigment while chlorophyll-b is the accessory pigment that collects energy and passes it on to chlorophyll-a.
 2. Chlorophyll-a absorbs energy from wavelengths of blue-violet and orange-red light while chlorophyll-b absorbs energy from wavelengths of green light.
 3. Chlorophyll-a absorbs energy at 675nm while chlorophyll-b absorbs energy at 640 nm.
 4. Chlorophyll-b is more absorbent than chlorophyll-a.
 5. Chlorophyll-a is the reaction center of the antenna array of core proteins while chlorophyll-b regulates the size of the antenna.
- Carotenoids (carotene and xanthophyll) absorb light in other spectrum regions and transfer that energy to chlorophyll for photosynthesis
- Packed into functional clusters, called photosystems, of two types: PSI and PSII (Z Scheme)
- Photosystems interact, trap solar energy, and convert it to chemical energy, called assimilatory power (ATP and NADPH_2)

Photochemical and Biosynthetic Phase

- Entire process within chloroplast
- Light-dependent (Light Reactions) and Light-independent (Dark reactions) take place at different sites in the same organelle
- Light reactions or electron transport chain (ETC)
 - Electrons are excited to higher level by absorbing light photons.
 - Electrons are accepted by electron acceptors and then reduced leaving PSII and PSI molecules in an excited state.
 - Electrons travel downhill in terms of energy in series of oxidation-reduction reactions resulting in formation of ATP and reduction of NADP to NADPH₂.
 - The assimilatory power (ATP and NADPH₂) moves out of the thylakoid into the stroma of the chloroplast.

Photosystem Differences

Photosystem I	Photosystem II
PS I has a reaction center of chlorophyll 'a' molecule with maximum light absorption at 700 nm wavelength, P ₇₀₀ .	PS II has a reaction center of chlorophyll 'a' molecule with maximum light absorption at 680 nm, P ₆₈₀ .
Primary electron acceptor is an iron protein (Fe-S-protein)	Primary electron acceptor, pheophytin, is a modified chlorophyll-a molecule with 2 hydrogen atoms in place of magnesium ion.
A set of electron carriers are plastocyanin, ferredoxin and cytochrome.	A set of electron carriers are pheophytin, plastoquinone, and cytochromes.
Generates strong reductant (weak oxidant) $\text{NADP}^+ + \text{H}^+ + 2\text{e}^- \rightarrow \text{NADPH}$	Generates strong oxidant (weak reductant) $2\text{H}_2\text{O} \rightarrow \text{O}_2 + 4\text{H}^+ + 4\text{e}^-$
Occurs mainly in unstacked stroma lamellae, in contact with stroma, where it has access to NADP ⁺	Occurs almost exclusively between stacked grana, out of direct contact with stroma

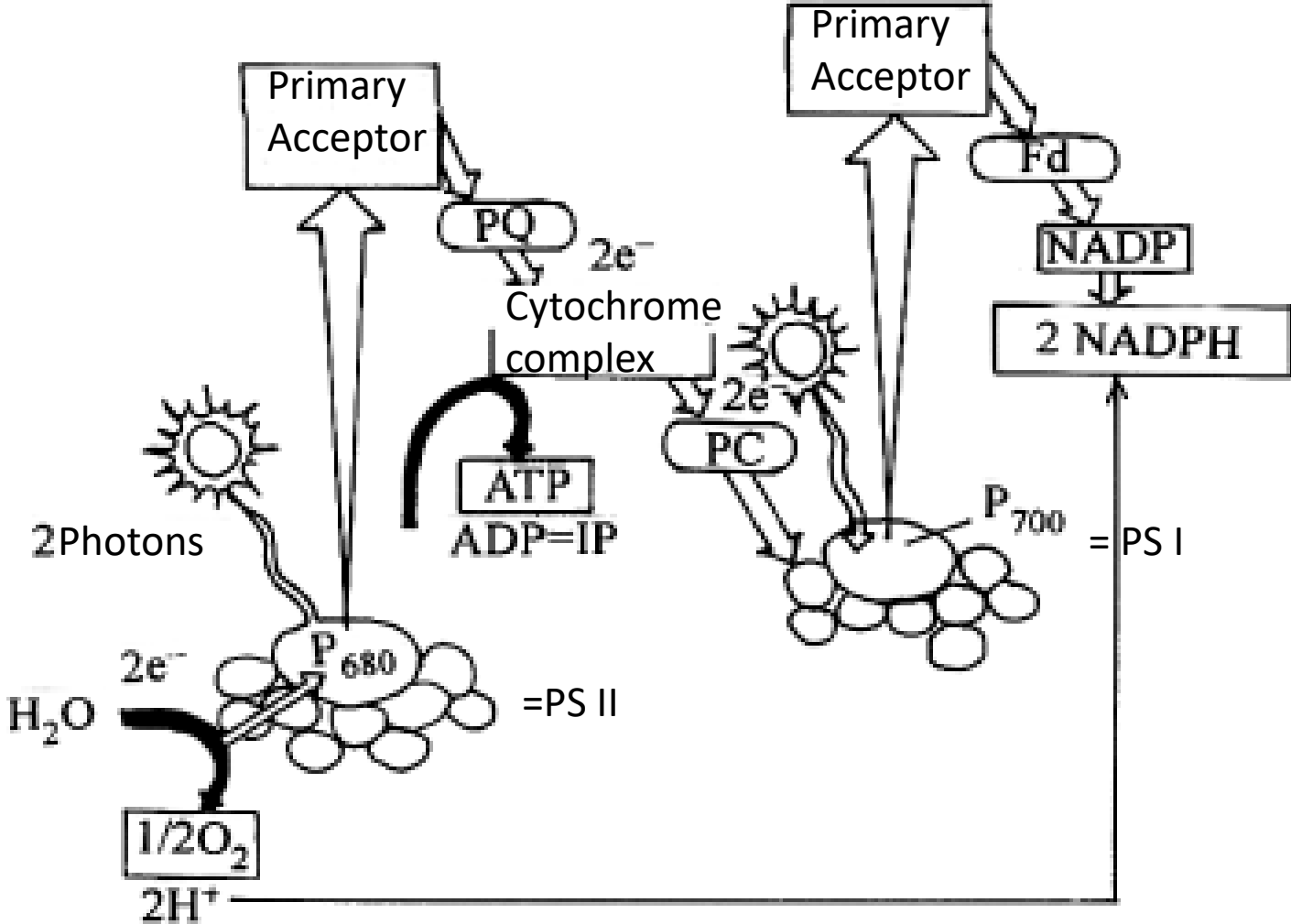
Thylakoid Transmembrane Protein Complexes

1. **PSII - P680** (Chl *a*), Pheo *a*, Q_A, Q_B
2. **Cytochrome *b₆f* complex** - (resembles cyt *bc*₁ and Complex III) cyt *f*, cyt *b*₆ (2 hemes), [2Fe2S] protein, bound plastoquinol, transport H⁺ from outside to inside of thylakoid membrane using Q cycle. Generates much of the H⁺ gradient that drives ATP synthesis
3. **PSI** - 7 subunits (2 large, 5 small), P700, 100 to 200 Chl *a*, 12 to 16 **β-carotene**, 3 [4Fe-4S] clusters, 2 **phylloquinone** (vit K₁)

Intercomplex electron transfer between

- PSII and cyt *b₆f* by plastoquinone/plastoquinol (Q or PQ /QH₂)
- cyt *b₆f* and PSI by plastocyanin (PC, a peripheral membrane Cu metalloprotein)

Non-cyclic (Z-scheme) Photophosphorylation



PQ=Plastoquinone
 PC=Plastocyanin
 Fd=Ferredoxin
 NADP = Nicotinamide Adenine
 Dinucleotide Phosphate
 ATP = Adenosine triphosphate

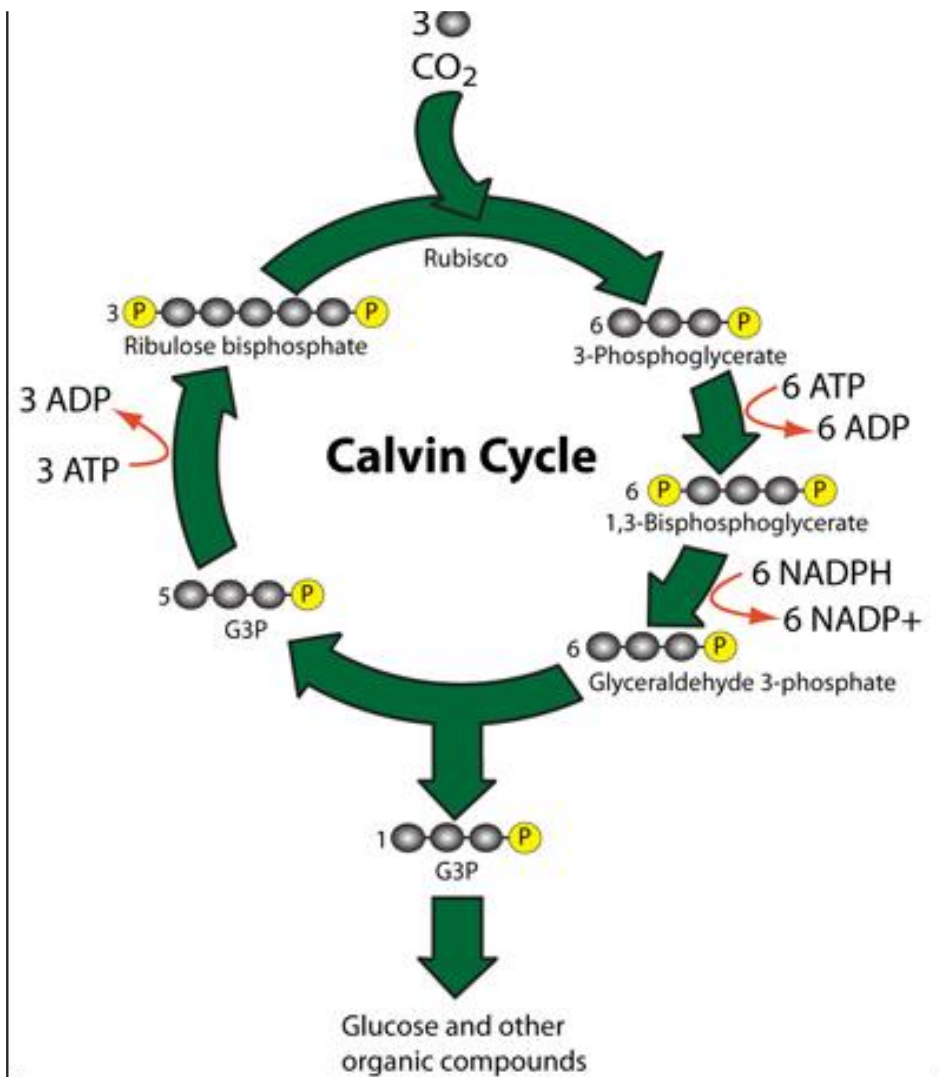
Dark Reactions

- Both NADPH_2 and ATP produced during light reaction are essential requirements for synthesis of carbohydrates.
- These series of reactions which catalyze the reduction of CO_2 to carbohydrates (also called fixation of CO_2) take place in the **stroma** of the chloroplast.
- These reactions are independent of light i.e. light is not necessary but can continue in light as well if products of the light reaction are available. Thus it is called a **dark reaction**.
- The carbon fixation reactions produce sugar in the leaves of the plant from where it is exported to other tissues of the plant as source of both organic molecule and energy for growth and metabolism.
- There are **two** major pathways by which CO_2 fixation (Dark reaction) takes place.

Dark Reaction Cycles

- C_3 Cycle (Calvin cycle)
 - (reductive pentose phosphate cycle)
 - $3CO_2 + 9ATP + 6NADPH \rightarrow$ glyceraldehyde-3-phosphate + $9ADP + 8P_i + 6NADP^+$
 - Precursor of higher carbohydrates (through nucleotide sugars):
 - sucrose (major transport sugar)
 - starch (major storage polysaccharide)
 - cellulose (primary structural polysaccharide)
 - precursor to fatty acids and amino acids
 - Uses enzymes from glycolytic, gluconeogenic, and pentosephosphate pathways
 - Three unique enzymes:
 - phosphoribulokinase
 - ribulose biphosphate carboxylase (RuBP carboxylase)
 - sedoheptulose biphosphatase (SBPase)
- C_4 Cycle (Hatch Slack Cycle) – Adaptation of plants in dry hot environment. Can photosynthesize in low CO_2 concentration and partial stomata closure.
 - Some C_4 plants – Sugar cane, corn, weeds

Calvin Cycle Summary



- Longer-term storage of energy from light reactions, ATP & NADPH
- Main purpose is to produce chemical “building block” **PGAL Glucose** (phosphoglyceraldehyde)
- Atmospheric CO₂ is used to make sugars like glucose and fructose
- Six-carbon Sugars made during the Calvin Cycle
- Occurs in the stroma

Summary

- Photosynthesis produces food from light, water, and carbon dioxide
- Only performed in living plant cells, chloroplasts
- Produces oxygen as byproduct that plants and animals use for respiration
 - Respiration uses oxygen, releases carbon dioxide and energy, and needs to happen continuously (day and night) for living aerobic plants and animals
- Photosynthesis is a complex process that has not been replicated outside of living plant cells
- Produces food that makes both plant and animal life possible
 - Simple carbohydrates produced in photosynthesis are transformed into lipids, proteins, nucleic acids and other organic molecules.

References

- Class Notes
 - UConn Master Gardener Program Botany Basics
- Internet
 - <http://www.nios.ac.in/media/documents/SrSec314NewE/Lesson-11.pdf>
 - http://www.siumed.edu/~eniederhoffer/bmb_courses/mbmb451b/lectures/mbmb451b_photosynthesis.pdf
 - <http://www.lyndhurstschools.net/userfiles/84/Classes/851/photosynthesis%20light%20&%20dark%20reactions%20ppt.pdf?id=560837>

Additional References

Internet

- http://cbc.chem.arizona.edu/classes/bioc460/spring/460web/lectures/Lec32_Photosynthesis2_07rlm.pdf
- [http://s3-euw1-ap-pe-ws4-cws-documents.ri-prod.s3.amazonaws.com/9780415584388/S9-1 \(RER2e-ch10-photosynthesis\).pdf](http://s3-euw1-ap-pe-ws4-cws-documents.ri-prod.s3.amazonaws.com/9780415584388/S9-1 (RER2e-ch10-photosynthesis).pdf)
- <https://www.ccrc.uga.edu/~rcarlson/bcmb3100/Chap23.pdf>
- <http://www.life.illinois.edu/govindjee/photosynBook/Chapter6.pdf>
- https://www.rose-hulman.edu/~brandt/Chem331/Photosynthesis_Light-Driven_Processes.pdf
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