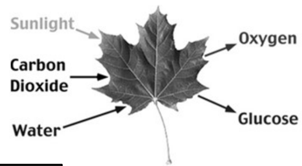
Photosynthesis: The BIG Picture

- **Photosynthesis is the process by which PHOTOAUTOTROPHS convert the energy in SUNLIGHT into the energy stored in ORGANIC COMPOUNDS.**

Don't forget the 1st Law of Thermodynamics, which says…

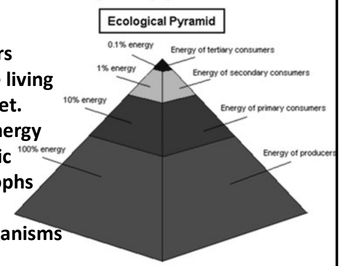
What is an *autotroph?*

What is an *organic compound?*



Photosynthesis & Ecology

- **The energy captured through photosynthesis forms the basis of the ecological pyramid.**
  - **The biomass that is generated by producers supports nearly all the living organisms on the planet.**
  - **Autotrophs capture energy and "fix" it into organic compounds; heterotrophs consume compounds produced by other organisms to obtain energy.**



Leaves: The Photosynthetic Organs of Plants

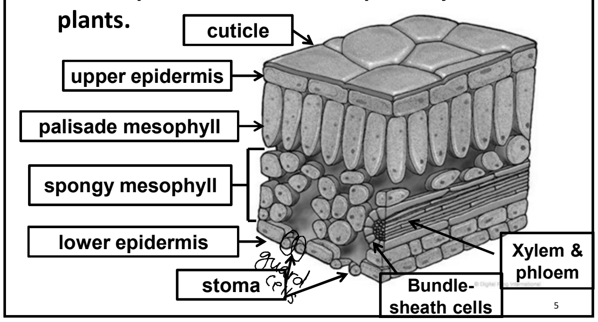
- **Leaves have a LOT of surface area to facilitate absorption of sunlight.**

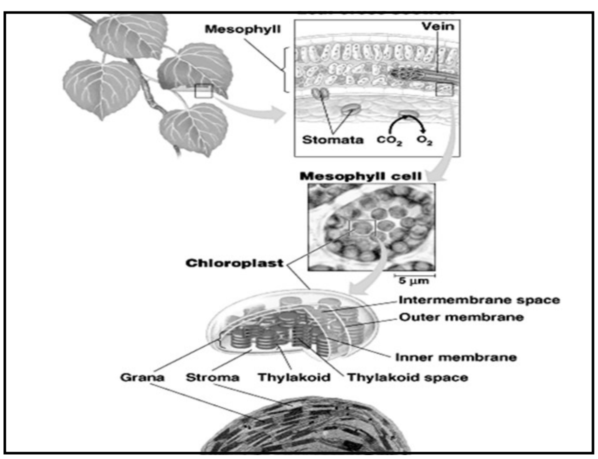
Are there any drawbacks to leaves having a large amount of surface area?

Leaves: The Photosynthetic Organs of Plants

mesophyll cell = typical plant cell

- **Leaves perform most of the photosynthesis in plants.**

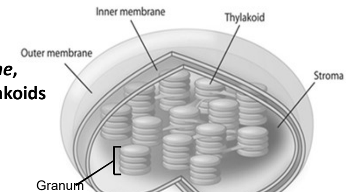




<u>Leaf Anatomy-Overview of PS</u>

Chloroplast Structure: A Review

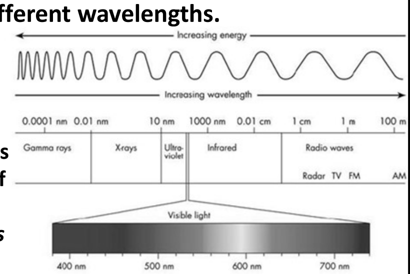
- In eukaryotes, photosynthesis takes place inside chloroplasts *inside* cells (inside *leaves*).
- Chloroplasts have 2 membranes:
  - *Outer* membrane
  - *Inner* membrane
    - *Thylakoid membrane*, folded to form thylakoids
    - Thylakoids are arranged in stacks called grana.



- Chlorophyll and other pigments involved in photosynthesis are embedded in the thylakoid membrane.

Light & Pigments

- Visible light is made up of different colors of light with different wavelengths.
- Light has a dual nature.
  - Light exhibits properties of both *waves* and *particles* (photons).



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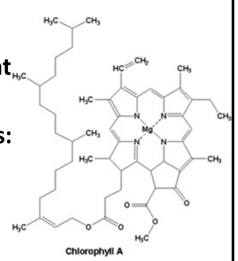
Light & Pigments

- Pigments are molecules that absorb light energy.
- Different pigments absorb light of different wavelengths.
- Major photosynthetic pigments:
  - Chlorophyll A
  - Chlorophyll B
  - Carotenoids
    - Xanthophyll – yellow
    - Carotenes – orange/red



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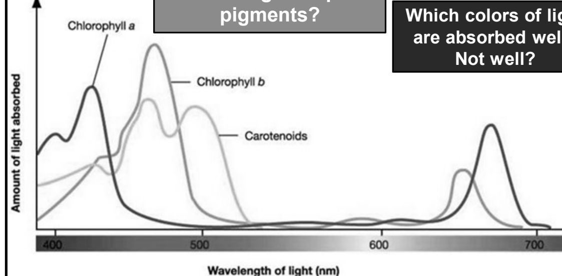
Light & Pigments

What is the advantage to having multiple pigments?

Which colors of light are absorbed well? Not well?



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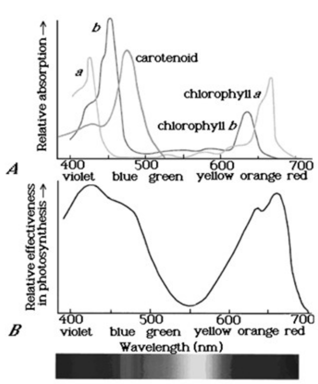
Light & Pigments

What information does this ABSORPTION SPECTRUM tell you?

What information does this ACTION SPECTRUM tell you?



Photosynthesis: An Overview

- The net overall equation for photosynthesis is:

$$6\,CO_2 + 6\,H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6\,O_2$$

- Photosynthesis occurs in 2 "stages":
  1. The Light Reactions (or Light-Dependent Reactions)
  2. The Calvin Cycle (or Calvin-Benson Cycle or Dark Reactions or Light-Independent Reactions)

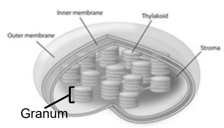
Is photosynthesis an ENDERGONIC or EXERGONIC reaction?

Photosynthesis: An Overview

- Follow the energy in photosynthesis,

light → Light Reactions (thylakoids) → ATP NADPH → Calvin Cycle (stroma) → Organic compounds (carbs)

light



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In Review

Click on the hyperlink below and choose "Animation" to begin the review.

http://media.pearsoncmg.com/bc/bc_0media_bio/bioflix/bioflix.htm?c7ephotosynthesis

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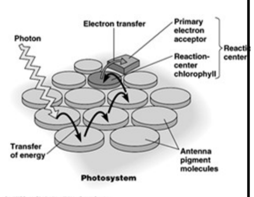
Phase 1: The Light Reactions

- The light reactions of photosynthesis involve the use of *photosystems.*
  - A photosystem is a cluster of pigment molecules bound to proteins, along with a primary electron acceptor.
  - 2 photosystems are involved:
    - Photosystem II (P680)
      - Absorbs light best at a wavelength of 680nm
    - Photosystem I (P700)
      - Absorbs light best at a wavelength of 700nm



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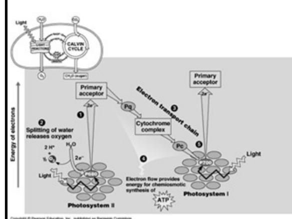
Phase 1: The Light Reactions

Non-Cyclic Electron Flow



1. Photosystem II [a group of pigment molecules] absorbs the energy in a photon [a particle of light], exciting an electron to a higher energy level.
   - Thus, PSII is now 1 electron SHORT of what it needs.
2. This electron is replaced by *photolysis* – the splitting of water using light.
   - O_2 is released as a byproduct.

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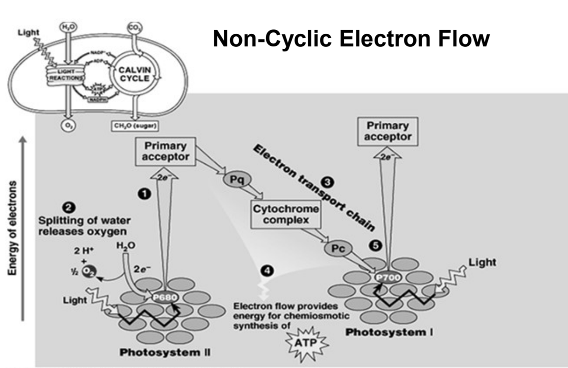
Phase 1: The Light Reactions

Non-Cyclic Electron Flow



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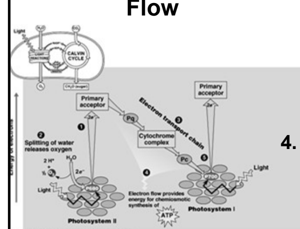
Phase 1: The Light Reactions

Non-Cyclic Electron Flow



3. The excited electron travels down the electron transport chain, made of increasingly electronegative cytochromes, "losing energy" as it goes. This energy is used to build a concentration gradient of protons [chemiosmosis].
4. At the same time, Photosystem I [another group of pigment molecules] also absorbs light energy, exciting one of ITS electrons to a higher energy level.

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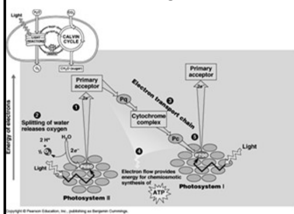
Phase 1: The Light Reactions

Non-Cyclic Electron Flow



5. The electron lost from Photosystem I is replaced by the electron that was excited and subsequently lost from Photosystem II.
6. The excited electron from Photosystem I travels down another electron transport chain, "losing energy" as it goes, and ultimately REDUCES $NADP^+$ to NADPH [an electron carrier].

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Phase 1: The Light Reactions

- **The energy LOST from the electrons as they travelled down the electron transport chain is used in the process of *chemiosmosis* to make ATP.**
- **What is ATP?!?**

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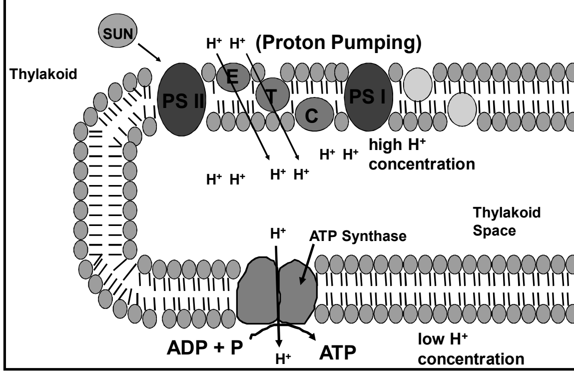
Chemiosmosis

- **Powers ATP synthesis**
- **Located in the thylakoid membranes**
- **Uses ETC and ATP synthase (enzyme) to make ATP**
- **Photophosphorylation: addition of phosphate to ADP to make ATP**

Chemiosmosis

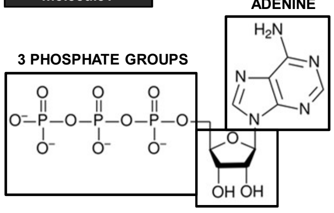


ATP

What are the 3 parts of an ATP molecule?

Why is ATP so unstable?

How is ATP used to do cellular work?



Phase 1: The Light Reactions

- **Protons (H^+) are pumped from the STROMA into the THYLAKOID SPACE, across the thylakoid membrane.**
  - This builds up a concentration of H^+ in the thylakoid space.
  - This concentration gradient represents POTENTIAL ENERGY.
- **In chemiosmosis, protons diffuse back to the stroma through ATP synthase.**
  - This is known as the proton motive force.
  - This causes ATP synthase to spin (like a turbine) and forces ADP and a phosphate group together.
    - This forms **ATP!**

What does the word "pumped" imply?

Where did the energy come from to do this?

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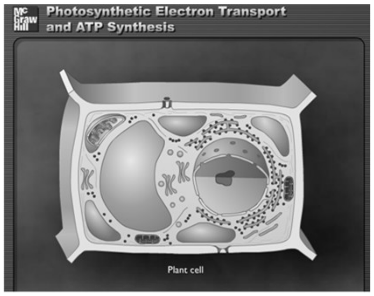
Phase 1: The Light Reactions



Light-Reactions Animation

Phase 1: The Light Reactions

- Quick recap:
  - In the light reactions, the energy in LIGHT is used to excite electrons to make ATP (through chemiosmosis) and produce NADPH (an electron carrier) to power the Calvin Cycle.
  - The light reactions occur in/across the thylakoid membrane inside the chloroplasts (inside the cells…)
  - Light and water are required (reactants).
  - Oxygen, ATP, and NADPH are produced (products).

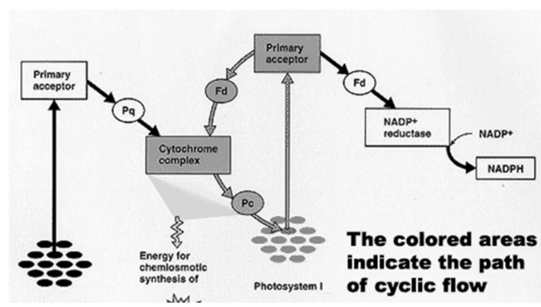
Phase 1: The Light Reactions

How could we know that?

- Cyclic electron flow
  - Cyclic phosphorylation is a more ancient biochemical pathway.
  - Most photosynthetic bacteria & all photosynthetic eukaryotes use cyclic phosphorylation.
  - Cyclic electron flow produces ATP, but does *not* produce NADPH.
    - Only photosystem I is used
    - Electrons are "recycled"
    - Water is *not* split

This is quite helpful because the Calvin Cycle requires more ATP than it does NADPH, so cyclic electron flow helps "make up" the difference!

Phase 1: The Light Reactions



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Phase 1:The Light Reactions

Non-Cyclic Electron Flow	Cyclic Electron Flow
2 photosystems (PS II & PS I) are used.	Only 1 photosystem (PS I) is used.
Water is split through photolysis to replace the "lost" electron.	Water is not split to replace electrons – the electron is "recycled" back to the photosystem.
Oxygen is released.	Oxygen is *not* released.
NADPH is produced.	NADPH is *not* produced.
ATP is produced.	ATP is produced.

Cyclic vs. Noncyclic Photophosphorylation Animation

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Phase 1: The Light Reactions

- Putting it all together…
  - The light reactions (light-dependent reactions) transfer the energy in sunlight into chemical energy in the form of ATP and NADPH, which are used to power the Calvin Cycle.
  - Light and water* are required for the light reactions to occur (reactants).
  - ATP, NADPH*, and oxygen gas (O_2)* are produced through the light reactions (products).

*Denotes items that are *not* produced during cyclic phosphorylation

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In Review

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http://media.pearsoncmg.com/bc/bc_0media_bio/bioflix/bioflix.htm?c7ephotosynthesis

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