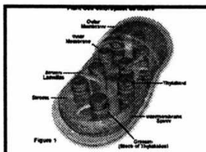
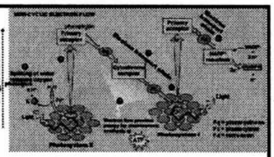
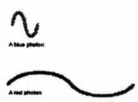




Photosynthesis



I. Photosynthesis and Nature

A. Sunlight is source of energy to produce carbohydrates.

B. Equation:

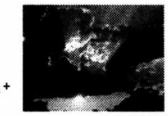
$6CO_2 + 12\,H_2O + \text{Light Energy} \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$

C. **Autotrophs**

1. Algae, plants, other protists, some bacteria
2. Ultimate source of food for life.
3. **Photoautotrophs**
4. **Chemoautotrophs**

D. **Heterotrophs** feed on autotrophs.

E. Photosynthesis produced most of the oxygen in the atmosphere of our planet.



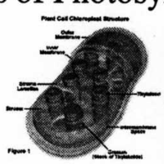
II. Structures of Photosynthesis

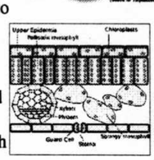
A. Chloroplasts

1. The sites of Photosynthesis
2. Leaf has most 500,000/mm^2
3. Mainly in the cells of the **mesophyll** (~30 to 40 per cell)

B. **Stroma**

1. Double membrane encloses a fluid-filled space
2. Contains enzyme-rich solution that reduces CO_2.





II. Structures of Photosynthesis

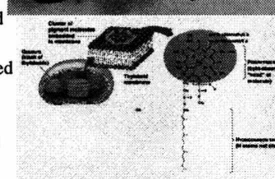
C. **Thylakoids**

1. Internal membranes within stroma
2. Organized into stacks called **grana**.
3. **Thylakoid Space:** Connected spaces within thylakoids

D. **Chlorophylls** and other pigments are embedded within thylakoid membranes.

E. Pigments absorb solar energy.

F. CO_2 enters and O_2 exits the leaf through openings called **stomata**.



III. Key Discoveries of Photosynthetic Process

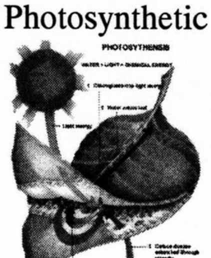
A. Overall equation for photosynthesis is usually stated as:

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

B. Seems like O_2 comes from splitting CO_2

C. C. B. van Niel(1930s)

1. Noticed bacteria that require hydrogen sulfide(H_2S) split CO_2 but don't give off O_2.
2. $CO_2 + 2H_2S \rightarrow CH_2O + 2S$
3. Hypothesized: oxygen given off by photosynthesis comes from water.



III. Key Discoveries of Photosynthetic Process

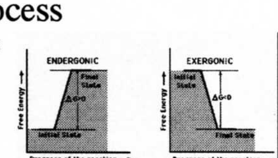
D. Proved 20 years later by using heavy oxygen(^{18}**O**)

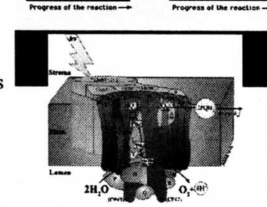
1. $CO_2 + 2H_2{}^*O \rightarrow CH_2O + H_2O + {}^*O_2$
2. $C^*O_2 + 2H_2O \rightarrow CH_2{}^*O + H_2O + O_2$

E. Electron flow is exergonic in cellular respiration.

F. Must be endergonic in photosynthesis.

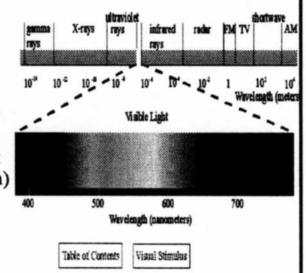
G. Energy provided by light splits water, providing the electrons to reduce CO_2 to a sugar





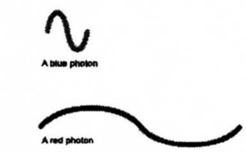
IV. The Nature of Sunlight

A. Solar radiation is electromagnetic energy
B. Described in terms of energy content and wavelength.
C. Electromagnetic Spectrum: range of solar radiation based on wavelength
   1. Gamma rays have shortest wavelength.(less than 1nm)
   2. Radio waves have longest wavelength(more than 1km)
   3. 380-750 nm is the visible spectrum for humans



IV. The Nature of Sunlight

D. **Photons**
   1. Discrete packets of radiant energy
   2. Travel in waves.
   3. Energy is inversely proportional to wavelength. (E= 1/wavelength)
E. UV radiation
   1. Short-wavelength
   2. High energy content
   3. Dangerous to cells, they can break chemical bonds



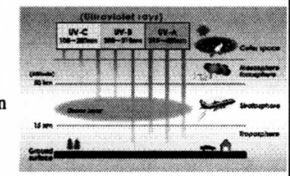
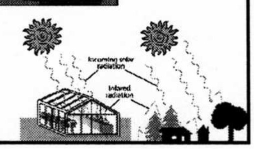


Figure 1. UV radiation at ground level

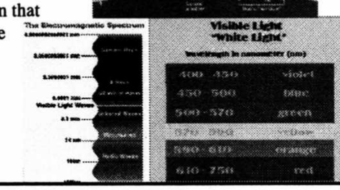
IV. The Nature of Sunlight

F. Infrared radiation
   1. Long-wavelength
   2. Low energy content.
   3. Do not damage cells because they do not break chemical bonds, only increase vibrational energy.
G. 42% of solar radiation that hits earth's atmosphere reaches surface; most is visible light.



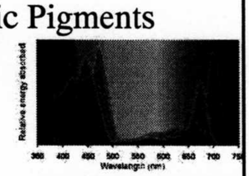
IV. The Nature of Sunlight

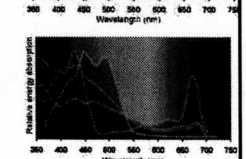
H. High energy wavelengths are screened out by ozone layer.
I. Low energy wavelengths are screened out by water vapor and CO_2.
J. Vision and photosynthesis, are adapted to radiation that is most prevalent in the environment.



V. Photosynthetic Pigments

A. Primarily use the visible light portion of the electromagnetic spectrum.
B. Major pigments are chlorophyll a and chlorophyll b.
   1. Both absorb violet, blue, and red wavelengths best.
   2. Most green is reflected back.
C. Carotinoids are yellow-orange pigments which absorb light in violet, blue, and green regions.
D. When chlorophyll in leaves breaks down in fall, the yellow-orange pigments show through.

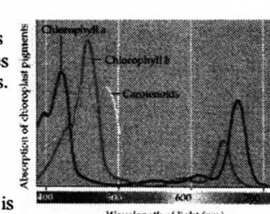




1. Beta-carotene(carrots)
2. Peridinin(dinoflagellates)
3. Fucoxanthin(kelp)

V. Photosynthetic Pigments

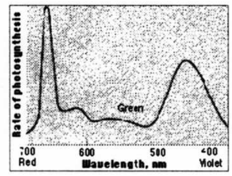
E. Absorption Spectrum
   1. Spectrophotometer: measures the amount of light that passes through a sample of pigments.
   2. As different wavelengths are passed through, some are absorbed.
   3. Graph of percent of light absorbed at each wavelength is the absorption spectrum.

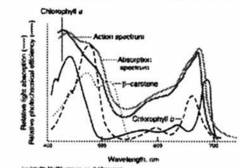


(a) Absorbance spectra

V. Photosynthetic Pigments

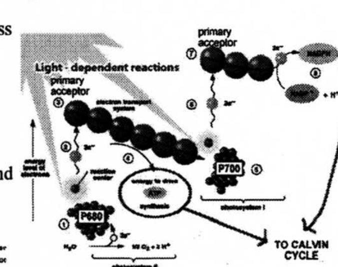
E. Action spectrum
1. Production of oxygen used to measure rate of photosynthesis.
2. Oxygen production is measured for plants under each specific wavelength and plotted on a graph.
3. Action spectrum resembles absorption spectrum; indicates chlorophylls contribute to photosynthesis.

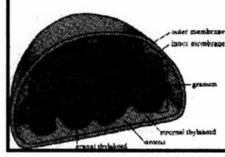




VI. Light-dependent Reactions

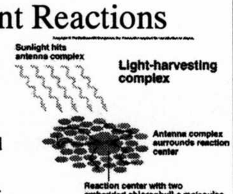
A. Cannot take place unless light is present.
B. Occur in the thylakoid membranes.
C. Requires two light-gathering units; photosystem I (PS I) and photosystem II (PS II)

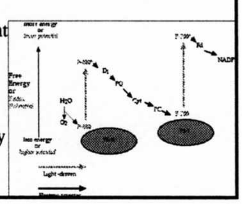




VI. Light-dependent Reactions

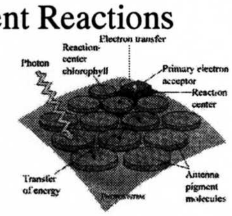
D. Photosystems
1. A pigment complex and electron acceptor.
2. Pigment complex composed of chlorophyll a and b molecules, and carotenoids
3. Solar energy is absorbed and high-energy electrons are generated.
4. Energy is passed from one pigment molecule to another until concentrated in reaction-center chlorophyll a.
5. Electrons in reaction-center chlorophyll a become excited; they escape to electron-acceptor molecule.

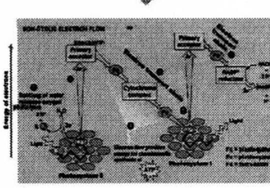




VI. Light-dependent Reactions

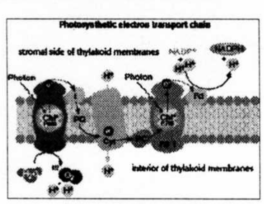
E. Noncyclic Electron Pathway
1. The PS II pigment complex absorbs solar energy
2. High-energy electrons (e-) leave the reaction-center chlorophyll a molecule(P680)
3. PS II takes replacement electrons from H_2O, which splits, releasing O_2 and H^+
4. The H^+ ions temporarily stay within the thylakoid space.
5. High-energy electrons that leave PS II are captured by an electron acceptor, which sends them to an electron transport system.

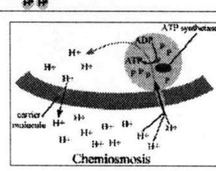




VI. Light-dependent Reactions

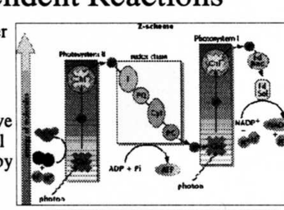
6. ATP Production
a) The thylakoid space acts as a reservoir for H+ ions; each time H_2O is split, two H^+ remain.
b) As electrons move carrier-to-carrier, they give up energy to pump H^+ from stroma into thylakoid space.
c) Chemiosmosis occurs forming ATP in the stroma.

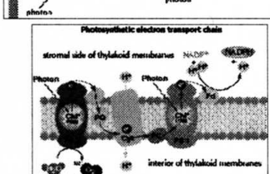




VI. Light-dependent Reactions

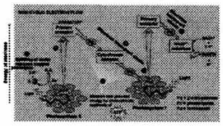
7. Low-energy electrons enter PS I.
8. PS I pigment complex absorbs solar energy
9. High-energy electrons leave reaction-center chlorophyll a(P700) and are captured by an electron acceptor.
10. The electron acceptor passes them on to $NADP^+$
11. $NADP^+$ takes on $2H^+$ to become NADPH + H^+
12. NADPH and ATP are used by enzymes in stroma during light-independent reactions.

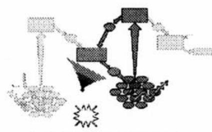


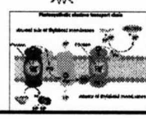


VI. Light-dependent Reactions

F. Cyclic Electron Pathway
1. PS I (P700) pigment complex absorbs solar energy.
2. High-energy electrons leave PS I reaction-center chlorophyll a molecule.
3. Electrons enter and travel down electron transport system.
4. Energy released is stored in form of a hydrogen (H^+) gradient.

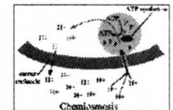


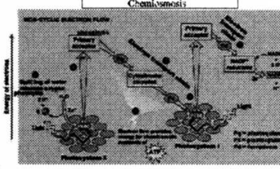




VI. Light-dependent Reactions

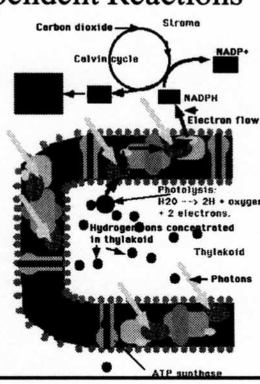
5. Chemiosmosis occurs forming ATP in the stroma
6. Some photosynthetic bacteria utilize cyclic electron pathway only; pathway probably evolved early.
7. Need more ATP than NADPH for Calvin Cycle.
8. NADPH concetration may influence which way electrons flow.
9. When CO_2 is in limited supply, carbohydrate is not being produced, no need for additional NADPH





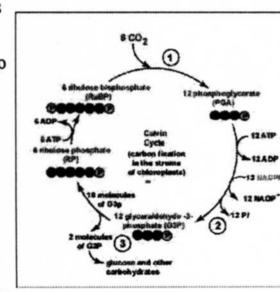
VII. Light-independent Reactions

A. Take place in the stroma
B. Occur in either the light or the dark.
C. Use NADPH and ATP to reduce CO_2.
D. Called the Calvin Cycle (C3 Cycle) after Melvin Calvin



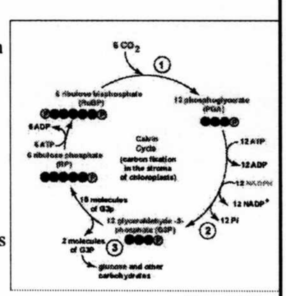
VII. Light-independent Reactions

E. Calvin Cycle Has Three Stages
1. Fixing Carbon Dioxide
   a) The attachment of CO_2 to an organic compound.
   b) RuBP (ribulose bisphosphate) is a five-carbon molecule that combines with carbon dioxide.
   c) Enzyme RuBP carboxylase(Rubisco) speeds reaction
   d) Rubisco is 20-50% protein in chloroplasts.



VII. Light-independent Reactions

2. Reducing PGA
   a) Six-carbon molecule immediately breaks down
   b) Forms two PGA (C3). Molecules (phosphoglycerate)
   c) Each PGA molecule undergoes reduction to PGAL (glyceraldehyde phosphate).
   d) Light-dependent reactions provide NADPH (electrons) and ATP (energy) to reduce PGA to PGAL.



VII. Light-independent Reactions

3. Regenerating RuBP
   a) Every three turns of Calvin cycle, five molecules of PGAL are used to re-form three molecules of RuBP.
   b) Every three turns of Calvin cycle, there is net gain of one PGAL molecule; five PGAL regenerate RuBP.
   c) First molecule identified by Calvin was PGA [C3], a three-carbon product; Calvin cycle is also known as C3 cycle