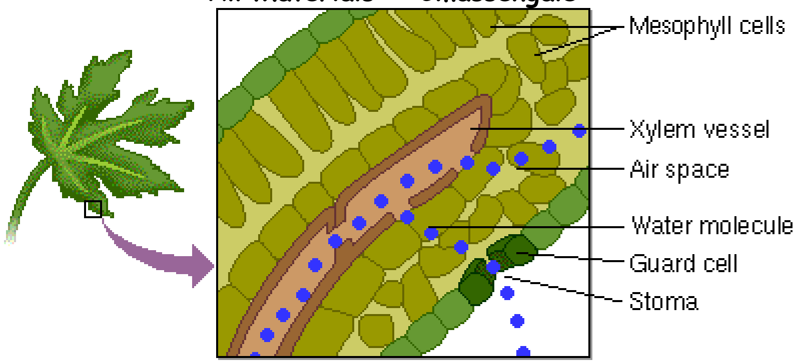
Photosynthesis



I. Capturing the Energy of Life

A. All organisms require *energy*

B. Some organisms (*autotrophs*) obtain energy *directly from the sun* and store it in organic compounds (*glucose*) during a process called*photosynthesis*

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

II. Energy for Life Processes

A. Energy is the *ability to do work*

B. Work for a cell includes *growth & repair, active transport across cell membranes, reproduction, synthesis of cellular products, etc.*

C. Work is the ability to change or move matter against other forces *(W = F x D)*

D. Autotrophs or producers convert sunlight, CO_2, and H_2O into glucose (their food)

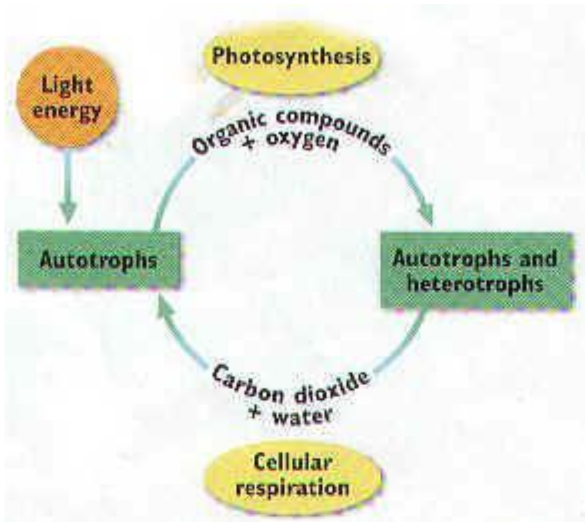
E. *Plants, algae, and blue-green bacteria, some prokaryotes*, are producers or autotrophs

F. Only 10% of the Earth's 40 million species are autotrophs

G. Other autotrophs use *inorganic compounds instead of sunlight* to make food; process known as *chemosynthesis*

H. Producers *make food for themselves and heterotrophs* or consumers that cannot make food for themselves

I. Heterotrophs include *animals, fungi, & some bacteria, & protists*



III. Biochemical Pathways

A. *Photosynthesis and cellular respiration* are biochemical pathways

B. Biochemical pathways are a series of reactions where the *product of one reaction is the reactant of the next*

C. *Only autotrophs* are capable of *photosynthesis*

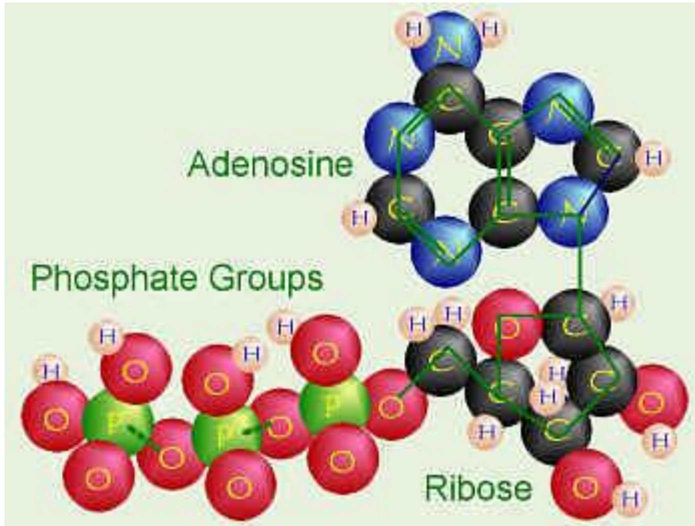
D. *Both autotrophs & heterotrophs* perform *cellular respiration* to release energy to do work

E. In photosynthesis, CO_2(carbon dioxide) and H_2O (water) are combined to form $C_6H_{12}O_6$ (glucose) & O_2 (oxygen)

$$6CO_2 + 6H_2O + \text{energy} \text{ --> } 6O_2 + C_6H_{12}O_6$$

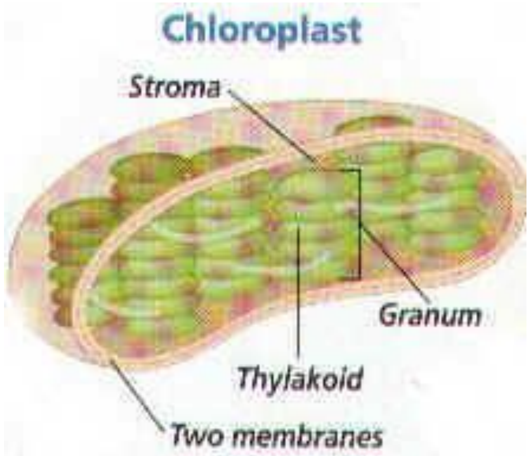
F. In cellular respiration, O_2 (oxygen) is used to burn $C_6H_{12}O_6$ (glucose) & release CO_2(carbon dioxide), H_2O (water), and energy

G. Usable energy released in cellular respiration is called adenosine triphosphate or *ATP*



IV. Light Absorption in Chloroplasts

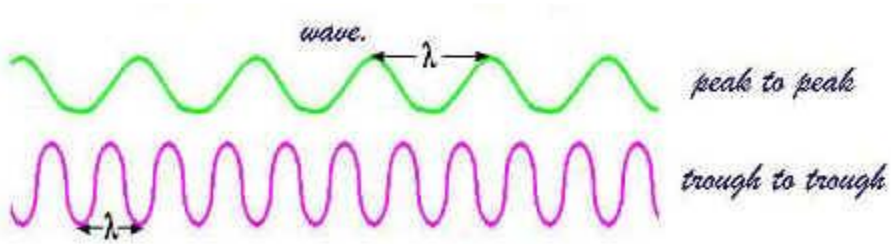
A. Chloroplasts in plant & algal cells absorb light energy from the sun during the light dependent reactions
B. Photosynthetic cells may have thousands of chloroplasts
C. Chloroplasts are double membrane organelles with the an inner membrane folded into disc-shaped sacs called *thylakoids*
D. Thylakoids, containing *chlorophyll* and other *accessory pigments*, are in stacks called *granum* (grana, plural)
E. Grana are connected to each other & surrounded by a gel-like material called *stroma*
F. Light-capturing pigments in the grana are organized into *photosystems*



V. Pigments

A. Light travels as waves & packets called *photons*

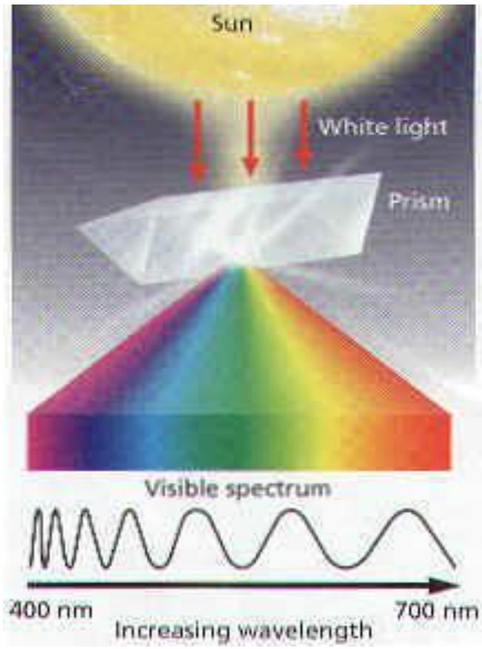
B. *Wavelength* of light is the distance between 2 consecutive peaks or troughs



C. *Sunlight or white light* is made of different wavelengths or colors carrying different amounts of *energy*

D. A *prism* separates white light into 7 colors (red, orange, yellow, green, blue, indigo, & violet) ROY G. BIV

E. These colors are called the *visible spectrum*

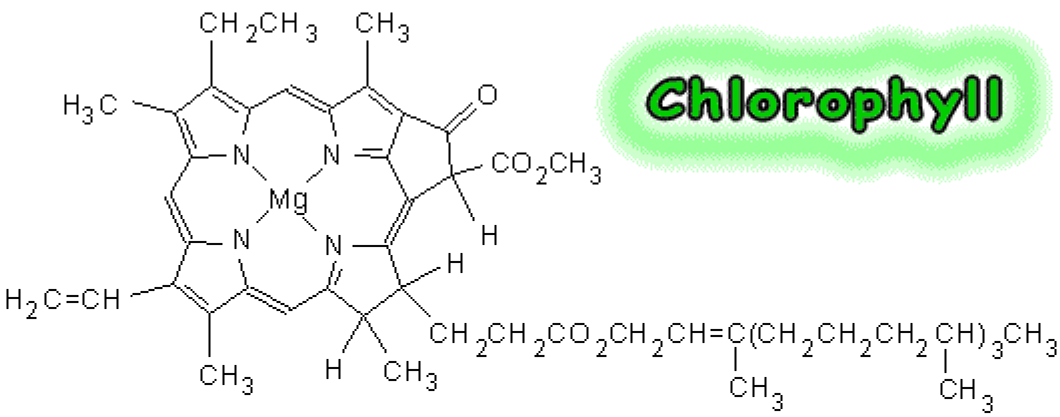


F. When light strikes an object, it is *absorbed, transmitted, or reflected*
G. When all colors are *absorbed*, the object appears *black*
H. When all colors are *reflected*, the object appears *white*
I. If only *one color is reflected* (green), the object *appears that color* (e.g. Chlorophyll)

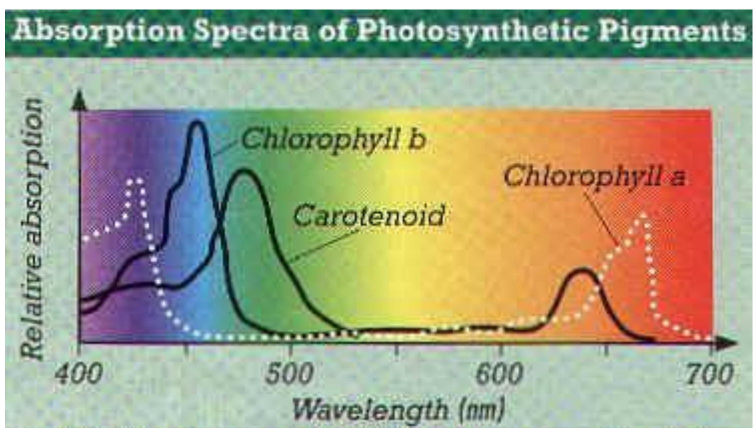
VI. Pigments in the Chloroplasts

A. Thylakoids contain a *variety of pigments* (green red, orange, yellow...)
B. *Chlorophyll* ($C_{55}H_{70}MgN_4O_6$) is the *most common pigment* in plants & algae
C. Chlorophyll *a* & chlorophyll *b* are the 2 most common types of chlorophyll in autotrophs
D. Chlorophyll absorbs only *red, blue, & violet light*
E. Chlorophyll *b* absorbs colors or light energy NOT absorbed by chlorophyll *a*

F. The light energy absorbed by chlorophyll b is transferred to chlorophyll *a* in the light reactions



G. *Carotenoids* are accessory pigments in the thylakoids & include *yellow, orange, & red*



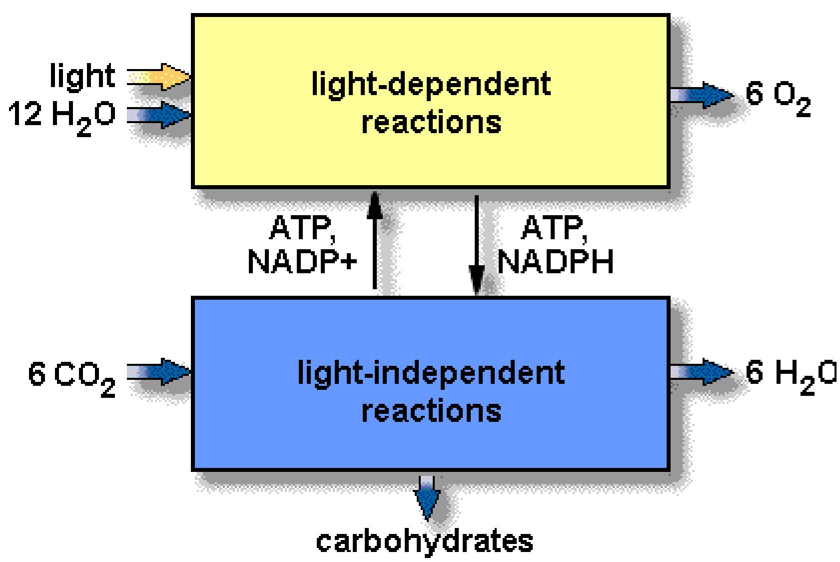
VII. Overview of Photosynthesis

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

A. Photosynthesis is not a simple one step reaction but a biochemical pathway involving many steps

B. This complex reaction can be broken down into two reaction systems --- *light dependent* & *light independent* or *dark reactions*

- **Light Reaction:** $H_2O \rightarrow O_2 + ATP + NADPH_2$
  - Water is split, giving off oxygen.
  - This system depends on sunlight for activation energy.
  - Light is absorbed by *chlorophyll a* which "excites" the electrons in the chlorophyll molecule.
  - Electrons are passed through a series of carriers and adenosine triphosphate or ATP (energy) is produced.
  - Takes place in the thylakoids.
- **Dark Reaction:** $ATP + NADPH_2 + CO_2 \rightarrow C_6H_{12}O_6$
  - Carbon dioxide is split, providing carbon to make sugars.
  - The ultimate product is glucose.
  - While this system depends on the products from the light reactions, it does not directly require light energy.
  - Includes the *Calvin Cycle*.
  - Takes place in the stroma.



VIII. Calvin Cycle

A. Carbon atoms from CO_2 are bonded or "fixed" into organic compounds during a process called *carbon fixation*
B. The energy stored in ATP and NADPH during the Light Reactions is used in the Calvin cycle
C. The Calvin cycle has *3 main steps* occurring within the *stroma* of the Chloroplast

STEP 1

- CO_2 diffuses into the stroma from surrounding cytosol
- An enzyme combines a CO_2 molecule with a five-carbon carbohydrate called RuBP
- The six-carbon molecule produced then splits immediately into a pair of three-carbon molecules known as PGA

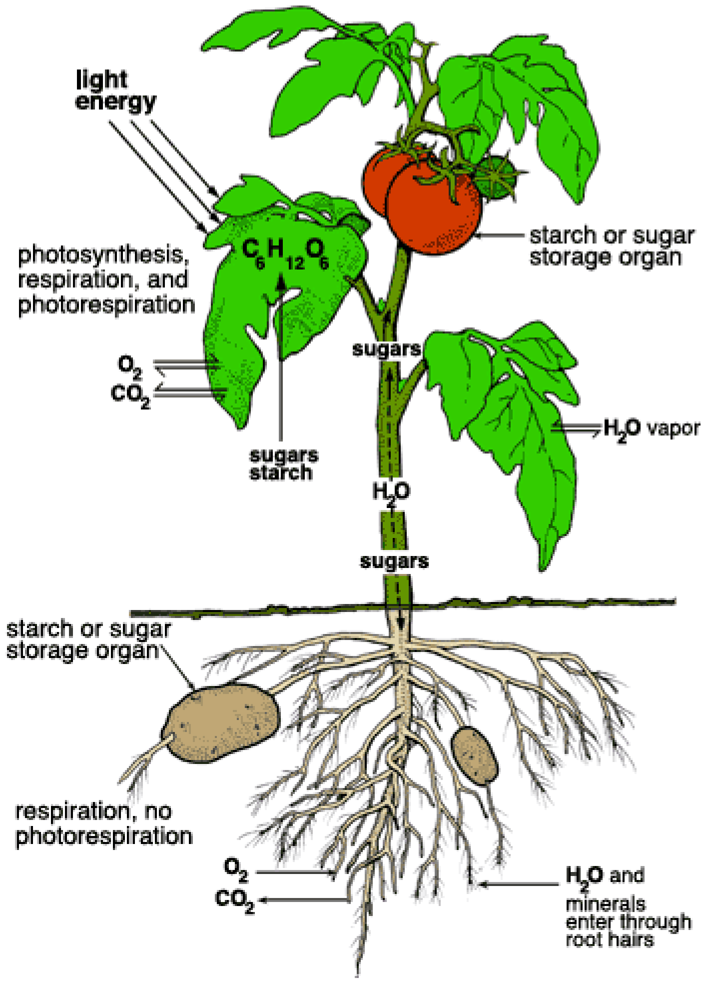
STEP 2

- Each PGA molecule receives a phosphate group from a molecule of ATP
- This compound then receives a proton from NADPH and releases a phosphate group producing PGAL
- These reactions produce ADP, NADP+, and phosphate which are used again in the Light Reactions.

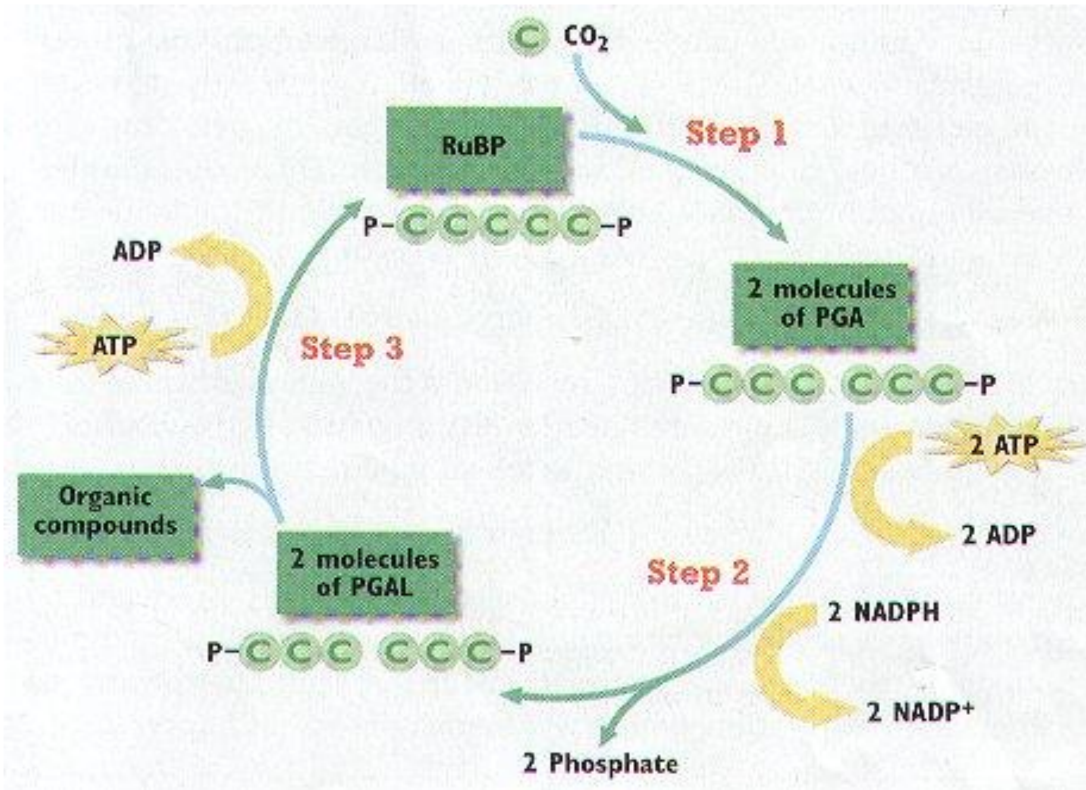
STEP 3

- Most PGAL is converted back to RuBP to keep the Calvin cycle going
- Some PGAL leaves the Calvin Cycle and is used to make other organic compounds including amino acids, lipids, and carbohydrates
- PGAL serves as the starting material for the synthesis of glucose and fructose

- Glucose and fructose make the disaccharide sucrose, which travels in solution to other parts of the plant (e.g., fruit, roots)



- Glucose is also the monomer used in the synthesis of the polysaccharides starch and cellulose



D. Each turn of the Calvin cycle fixes One CO_2 molecule so it takes six turns to make one molecule of glucose

IX. Photosystems & Electron Transport Chain

A. Only 1 in 250 chlorophyll molecules (chlorophyll *a*) actually converts light energy into usable energy
B. These molecules are called reaction-center chlorophyll
C. The other molecules (chlorophyll b, c, & d and carotenoids) absorb light energy and deliver it to the reaction-center molecule
D. These chlorophyll molecules are known as antenna pigments
E. A unit of several hundred antenna pigment molecules plus a reaction center is called a photosynthetic unit or photosystem
F. There are 2 types of photosystems --- Photosystem I & Photosystem II

G. Light is absorbed by the antenna pigments of photosystems II and I

H. The absorbed energy is transferred to the reaction center pigment, P_{680} in photosystem II, P_{700} in photosystem I

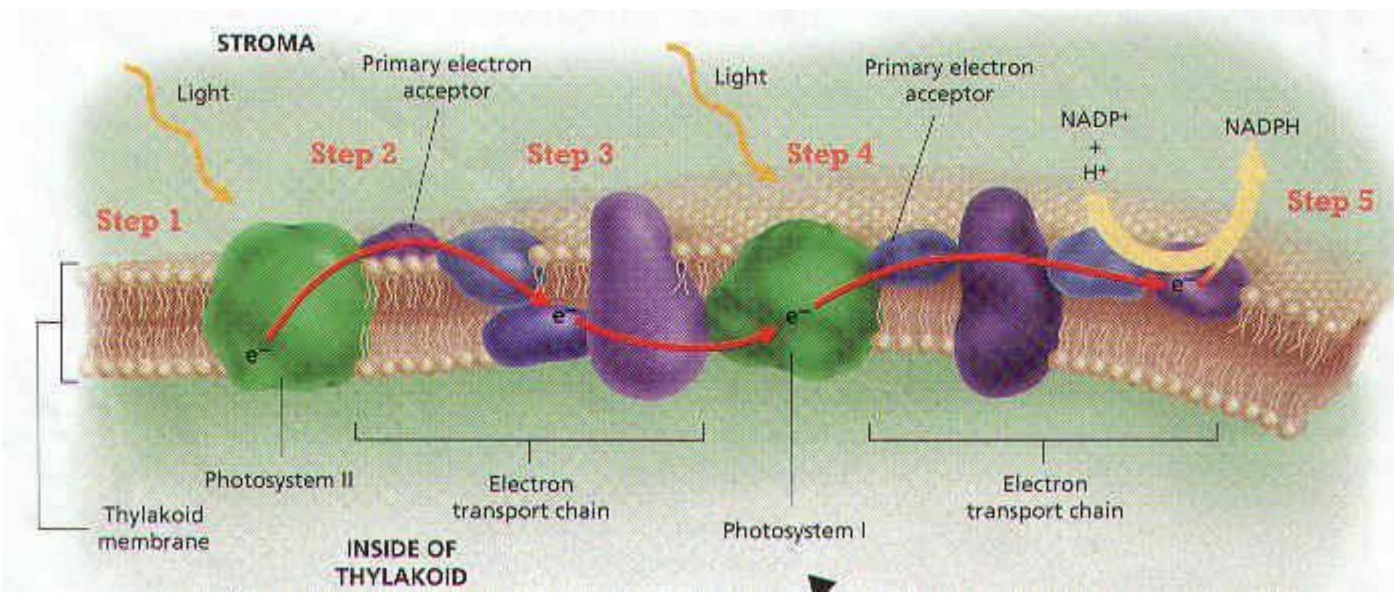
I. P_{680} in Photosystem II loses an electron and becomes positively charged so it can now split water & release electrons ($2H_2O \longrightarrow 4H^+ + 4e^- + O_2$)

J. Electrons from water are transferred to the cytochrome complex of Photosystem I

K. These excited electrons activate P_{700} in photosystem I which helps reduce $NADP^+$ to NADPH

L. NADPH is used in the Calvin cycle

M. Electrons from Photosystem II replace the electrons that leave chlorophyll molecules in Photosystem I

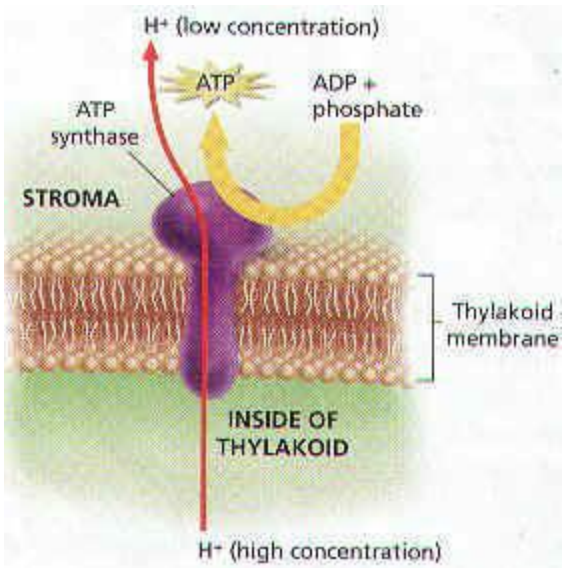


X. Chemiosmosis (KEM-ee-ahz-MOH-suhs)

A. Synthesis or making of ATP (energy)

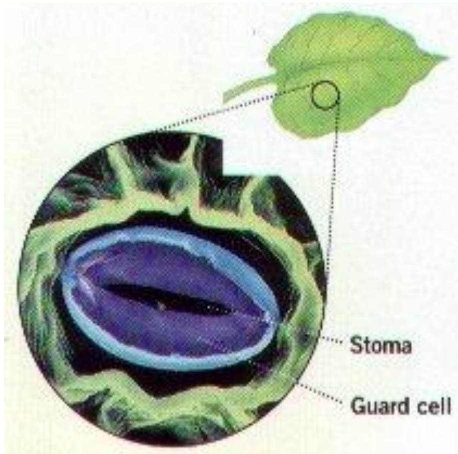
B. Depends on the concentration gradient of protons (H+) across the thylakoid membrane

C. Protons (H+) are produced from the splitting of water in Photosystem II
D. Concentration of Protons is HIGHER in the thylakoid than in the stroma
E. Enzyme, ATP synthetase in the thylakoid membrane, makes ATP by adding a phosphate group to ADP



XI. Alternate Pathways

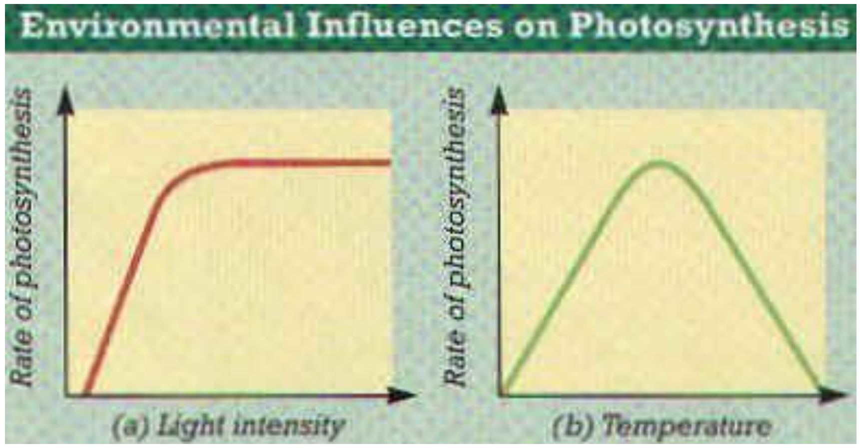
A. The Calvin cycle is the most common pathway used by autotrophs called C_3 Plants
B. Plants in hot, dry climates use alternate pathways to fix carbon & then transfer it to the Calvin cycle
C. Stomata are small openings on the underside of leaves for gas exchange (O_2 & CO_2)
D. Guard cells on each side of the stoma help open & close the stomata
E. Plants also lose H_2O through stoma so they are closed during the hottest part of the day



F. C_4 plants fix CO_2 into 4-Carbon Compounds during the hottest part of the day when their stomata are partially closed
G. C_4 plants include corn, sugar cane and crabgrass
H. CAM plants include cactus & pineapples
I. CAM plants open their stomata at night and close during the day so CO_2 is fixed at night
J. During the day, the CO_2 is released from these compounds and enters the Calvin Cycle

XII. Factors Determining the Rate of Photosynthesis

A. Light intensity - As light intensity increases, the rate of photosynthesis initially increases and then levels off to a plateau
B. Temperature - Only the dark, not the light reactions are temperature dependent because of the enzymes they use (25 °C to 37°C)
C. Length of day
D. Increasing the amount of carbon dioxide available improves the photosynthesis rate
E. Level of air pollution


Environmental Influences on Photosynthesis
Rate of photosynthesis
(a) Light intensity
Rate of photosynthesis
(b) Temperature