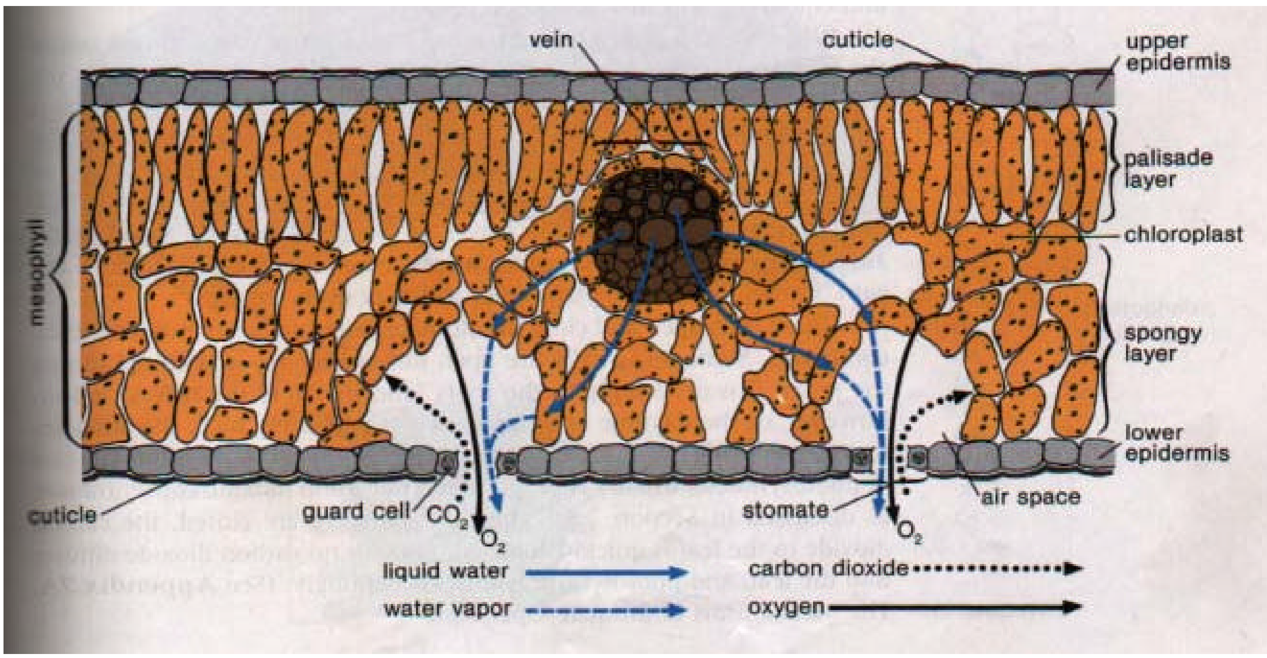
Chapter 7 – Photosynthesis – Harvesting Light Energy

1. **The Living Bridge** – Photosynthesis connects the sun and the organisms on Earth by providing energy
2. **Materials for Photosynthesis** – CO_2, water, sunlight
3. **Products of Photosynthesis** – O_2, the carbon building blocks of cells and tissues, plants, our food supply
4. **Equation for Photosynthesis** – $6CO_2 + 6H_2O \dashrightarrow C_6H_{12}O_6 + 6O_2$
5. **Ancient Photosynthesis Byproducts** – supplies us with petroleum, oil, coal
6. **Origin of Photosynthesis** – The first organisms were heterotrophs (Heterotroph Hypothesis)
   As food became scarce, some organisms adapted and found an alternate source of food – sunlight
   First "plants" made their own food, but supplemented with other organisms
   Certain bacteria are true heterotrophs, others and half and half
   Eventually, photosynthetic bacteria became part of eukaryotic cells and evolved to become chloroplast
7. **The Visible Light Spectrum** – wavelengths of light that the human eye can detect

Red	Orange	Yellow	Green	Blue	Violet
650 – 700nm	600 – 650nm	550 – 600nm	500 – 550nm	450 – 500nm	400 – 450nm

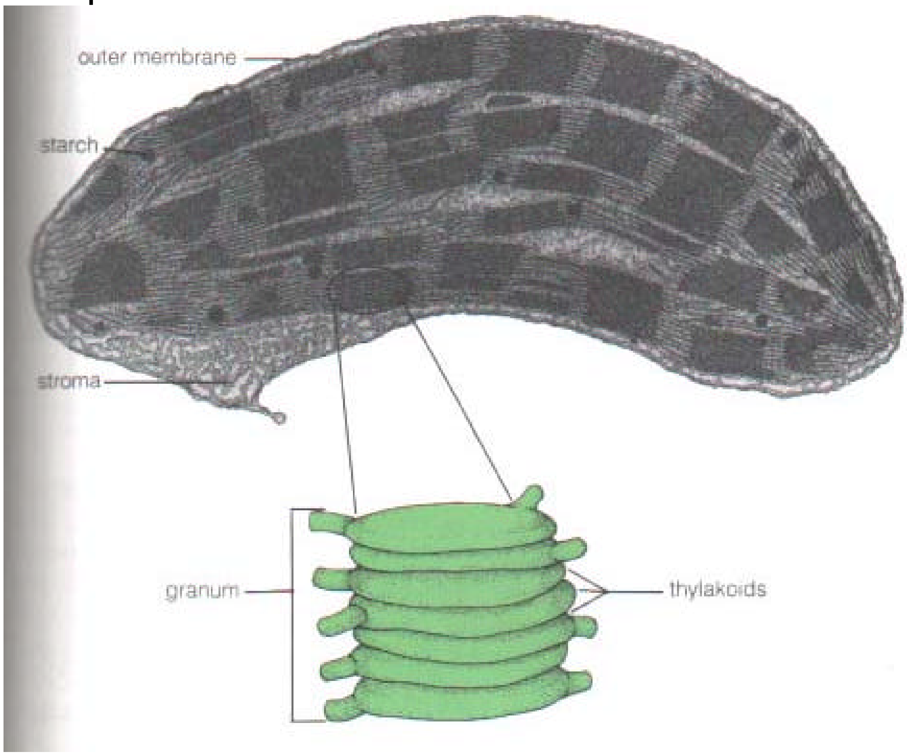
   The **green** and **yellow** portions of the visible light spectrum reflects green light, absorbs other colors
8. **Leaf Structure** – leaves are made to maximize the efficiency of photosynthesis



Upper and Lower epidermis – single layer of cells to protect the leaf
   The lower epidermis contains stomates
   The epidermis secretes a waxy substance known as the cuticle
Cuticle – a water repellent covering that controls the amount of water in the cell
Palisade Layer – Most of the choloroplasts are here
Spongy Layer – more open space than the palisade layer, absorbs light that passes through Palisade
   Spaces allow CO_2, O_2, and $H_2$0 vapor to diffuse
Chloroplast – sacks of chlorophyll, which convert sunlight into glucose through photosynthesis
Stomates – small pores in the lower epidermis. Controls the diffusion of gasses into and out of the cell
   The stomata contains a pore and two guard cells. Open during the day, closed at night
Guard Cells – When they swell with water, the pore opens, and gasses diffuse through
   Contains chloroplast, thus, able to photosynthesize
Vein – a "plumbing system" that transports water and minerals to the cells and removes waste (oxygen)
Mesophyll – a photosynthetic tissue known as mesophyll. Consists of palisade and spongy layers
   Air spaces in mesophyll act as reservoirs for CO_2 and $H_2$0 vapor
Transpiration – evaporation of water from the leaf – major source of water loss for plants
   When stomates open, water is lost. On a hot day, stomates close to conserve water.
   Plants wilt when rate of transpiration exceeds the rate of which water is absorbed by roots

The Leaf is an excellent example of how structure is related to function

9. **Chloroplast structure**



Outer membrane – controls the flow of materials
Internal Membrane – consists of sacks, of thylakoids, which increase membrane surface area
Thylakoids – increases inner membrane surface area. Thylakioids are stacked.
Contains light absorbing pigments and enzymes
Grana – stacks of thylakoids. Arranged for maximum absorption of light
Stroma – contains enzymes, DNA, RNA, ribosomes, surrounds thylakoids. DNA similar to bacteria DNA
Chlorophyll – a green pigment, present in two forms, A and B. Absorbs the extremes of visible light
Green plants have pigments to work with chlorophylls to absorb additional wavelengths of light
Absorbed light energy is transferred to a special type of chlorophyll a for use in photosynthesis
As chlorophyll content declines, some accessory pigments become the dominant light absorbers
Responsible for the change of colors of leaves in the fall
Accessory pigments – Carotine – orange, Xyanthophyll – yellow, Anthocyanin - red

10. **The Process of Photosynthesis** – Absorption of light, conversion of light to chemical energy, storage in sugars
11. **The Light Reactions** – thylakoids absorb light; convert it to chemical NRG carried by unstable molecules
    1. Thylakoids absorb light
    2. H2O is split into H_2 and O_2, O_2 is released into the atmosphere
    3. Light energy is stored as chemical energy
    4. **Photosystem I and II** – distinct groups of pigments, embedded in the thylakoid membranes

Protein molecules carry electrons between the two photosystems
PSI consists of several hundred molecules of chlorophyll and other pigments that absorb light
NRG transferred to a special chlorophyll a molecule, the **reaction center**.
Reaction Center – only molecule that can participate directly in electron flow in light reactions
Associated with particular proteins and other membrane components
Special due to its chemical environment
In each photosystem, the reaction center loses electrons, which are captured by electron carriers
Flow of electrons established. Proteins act as electron carriers.
Electrons from photosystem I are replaced by electrons lost from photosystem II
Electrons lost from photosystem II are replaced by electrons lost from water
Photosystem II splits water $H_2O \dashrightarrow 2H^+ + 2e^- + ½O_2$
$NADP^+$ - Nicotinamide adenine dicucleotide phosphate – a hydrogen carrier
Combines with electrons and protons to form NADPH
NADPH – a short-lived NRG molecule, used to transfer NRG to calvin cycle
As electrons flow, some NRG is sued to actively transport protons across thylakoid membrane
Results in high concentration of protons inside thylakoid, but cannot maintain
Creates conc gradient, passes through **ATP synthetase,** synthesizes ATP from ADP+P

12. **The Dark Reactions – The Calvin Cycle** – turns ATP, NADPH, and CO_2 into Glucose ($C_6H_{12}O_6$)
Necessary because ATP and NADPH aren't stable, and cannot be directly used as carbon skeletons
The Steps of the Calvin Cycle
1. CO_2+ RuBP (Ribulose bisphosphate. Known as carbon dioxide fixation) ✍ 6 C molecule (Citric Acid)
2. 6 C molecule --> 2 three carbon molecules, PGA (phophoglyceric Acid
3. PGA + ATP + NADPH --> PGAL (3 Carbon compound, phosphoglyceraldehyde)
   This reaction happens twice, since there are two molecules of PGA in each cycle
4. PGAL undergoes a series of reactions that form several 4, 5, and 6 carbon phosphates
5. Final step uses 1 ATP molecule to regenerate RuBP from a 5 carbon sugar phospate,
6. Cycle repeats 3 times, each incorporating one molecule of CO2, forms 6 molecules of PGAL
7. 5 of the 6 molecules of PGAL are required to regenerate RuBP, 1 is available to form Glucose

Rubisco – enzyme that catalyzes the reaction that incorporates CO2 into the cycle, or onto PGA
C_3 Plants - plants that use the Calvin cycle exclusively to fix CO_2
The Calvin Cycle cannot operate in the dark. Light activates rubisco and several other enzymes. No CO_2 in dark

13. **Products of the Calvin Cycle** – Glucose, Sucrose, and other sugars
Other cell processes use PGAL to make other sugars, such as glucose, sucrose and starch
Chloroplasts break down starch at night to supply NRG when there is no light
PGAL and other sugar phosphates from the Calvin cycle are food for the plant
14. **Rates of Photosynthesis**– Photosynthesis is most efficient at certain conditions
1. Concentration of CO_2, O_2 – As CO_2 increases, rate increases. As O_2 increases, rate decreases
   After a certain point, more CO_2 will not increase rate any further
2. **Temperature** – Bell curve. Temp and rate increase, but past a certain point, rates decrease
   Optimum temperatures are between 20 and 30 degrees Celsius
3. **Amount of Light** – the more intense the light, the faster the rate
   Light Saturation Point – Any more light past this point doesn't increase rate of photosynthesis
4. Rates can be measured by measuring amount of O_2 produced or CO_2 consumed over time
5. **Limiting Factors** – although one criteria may be optimum, another is inhibiting
   At max light intensity, a lower temperature will slow rate, making temperature a limiting factor
   Light is a limiting factor in the oceans, temperature in the desert, etc

15. **Photorespiration and Photosynthesis**– Oxygen and inhibit the process
Rubisco can bind with either CO_2 or O_2. CO_2 + RuBP + Rubisco --> 2PGA
Photorespiration - Rubisco + O_2 + RuBP --> 1PGA + 1 molecule of ghycolate (2 carbon Acid)
When rubisco binds with O_2, no new CO_2 is fixed, and RuBP is converted to CO2, photosynthesis slows
Photorespiration and Photosynthesis occur simultaneously.
High levels of CO_2 favor photosynthesis, high levels of O_2 favor photorespiration
Photorespiration basically undoes what photosynthesis does and inhibits the Calvin cycle
16. **C_3 and C_4 plants** – C_3 are normal plants, normal photosynthesis. C_4 is a special type of photosynthesis
Used in hot, dry, weather. CO_2 is incorporated in 4 carbon acid instead of PGA.
Differences from C_3 plants
Bundle sheath – layer a tightly packed cells around veins, surrounded by mesophyll cells
Contains two systems of CO_2 fixation.
1. In mesophyll cells, fixes CO_2 by combining with 3 carbon acid
2. Resulting 4 carbon acid rearranged and transported to bundle sheath cells
3. In bundle sheath cells, CO_2 released from 4 carbon acid, refixed by rubsico, PGA

By delivering CO_2 to the bundle sheath cells, CO_2 conc inside the bundle sheath cells is high
Able to overcome photorespiration even at high temperatures
Function at maximum efficiency without opening stomates, preventing water loss
C3 plants cannot operate efficiently at high temperatures
C4 plants grow more rapidly than C_3 plants, especially in warm climates
C4 plants can be twice as efficient as photosynthesis'
Most foods, such as soybeans, wheat, and rice, are C_3, so it's not very efficient
17. **CAM plants**– Crassulacean Acid Metabolism – important for dry areas
Absorbs CO_2 at night, stomates close during the day. These plants tend to grow very slowly

18. Photosynthesis is 3.5 billion years old. Proved by fossil records
19. As CO_2 levels rise due to fires and factories, trees are being burned, less plants to absorb CO_2
As CO_2 builds in the atmosphere, it traps heat, greenhouse effect

Chapter 7 – Important Concepts

1. Explain why photosynthesis is considered to be so important for the existence of life on Earth

   Since all living organisms, at least complex ones, require oxygen, photosynthesis is required to absorb carbon dioxide and release oxygen. Oxygen is also used to create ozone in the upper atmosphere to shield the Earth's surface from the sun's ultraviolet rays. Furthermore, photosynthesis produces sugars such as glucose, sucrose, and other forms of chemical energy, which other organism eat. Without photosynthesis as a renewable source of energy, the Earth would soon run out of food and usable energy.

2. Draw and label the cross section of a leaf

   See leaf picture on page 1

3. Explain how a typical leaf is perfectly designed to be a photosynthetic machine

   The large surface area of the leaf allows the leaf to absorb the maximum amount of sunlight. The palisade layer, where the majority of photosynthesis takes place, is near the surface to minimize the amount of light lost. The spongy layer below absorbs light that passes through the palisade layer in order to further utilize all absorbed light. The spaces in the spongy layer allow CO_2 and O_2 to easily diffuse in and out of the cell

4. Describe the structure and function of a chloroplast and explain how leaves change color in the fall

   Chloroplast are the "cells" responsible for photosynthesis. Chloroplasts contain an outer membrane that regulates the flow of materials into and out of the "cell." The inner membrane contains thykaloids, which maximize the surface area of the membrane. Thykaloids are stacked together to form grana, which are arranged for maximize the amount of light absorbed. The green pigments responsible for absorbing light are embedded in the thykaloids. During most of the year, the primary pigment is chlorophyll, which reflects green light, so plants appear green. However, in the fall, as chlorophyll levels decrease, the primary pigment varies, and the leaves change colors accordingly.

5. Write the balanced chemical equation for photosynthesis

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

6. List the primary functions of the light reactions and the Dark Reactions of photosynthesis

   The light reactions absorb light and water and convert the light energy into chemical energy, in the forms of ATP and NADPH. In the process, oxygen is also released. The dark reactions, consisting of the Calvin Cycle, take carbon dioxide and the ATP and NADPH produced during the light reactions to form energy storing compounds such as glucose and sucrose

7. Explain how photosystem I, II, and the Calvin Cycle relate to one another

   Photosystem I and photosystem II are methods of capturing sunlight, and transferring the energy to a special chlorophyll a molecule known as the reaction center. There, a flow of electrons is created, with photosystem II resupplying photosystem I's lost electrons. Ultimately, they produce ATP and NADPH, which is used in the Calvin Cycle to create glucose and sucrose

8. Name and describe the four major factors that directly affect the rate of photosynthesis

   Concentration of O_2 and CO_2 – as CO_2 increases, rate increases. O_2 increases, rate decreases
   Light intensity – the amount of light received. More light, faster rate, but levels off after light sat. point
   Temperature – bell curve. 20 – 30 degrees Celsius is the optimal range for photosynthesis

9. Explain the differences between C_3 and C_4 plants

   C_4 plants are designed to survive in hot, arid climates, where C_3 plants would die. By using a two step fixation of carbon, a C_4 plant is able to keep its stomates closed during the day, thus slowing water loss. Also, C_4 plants can photosynthesize much quicker than C_3 plants, and also grow at a much higher rate.

10. Describe how photosynthesis and the greenhouse effect are interrelated

    As the rain forests are being burned, the amount of CO_2 in the air is increasing. However, as trees are destroyed, there are less plants to absorb the CO_2, thus increasing the CO_2 concentration in the air. The CO_2 acts as a blanket, trapping the heat from the sun, causing the surface temperature to rise. This phenomena is known as the green house effect.