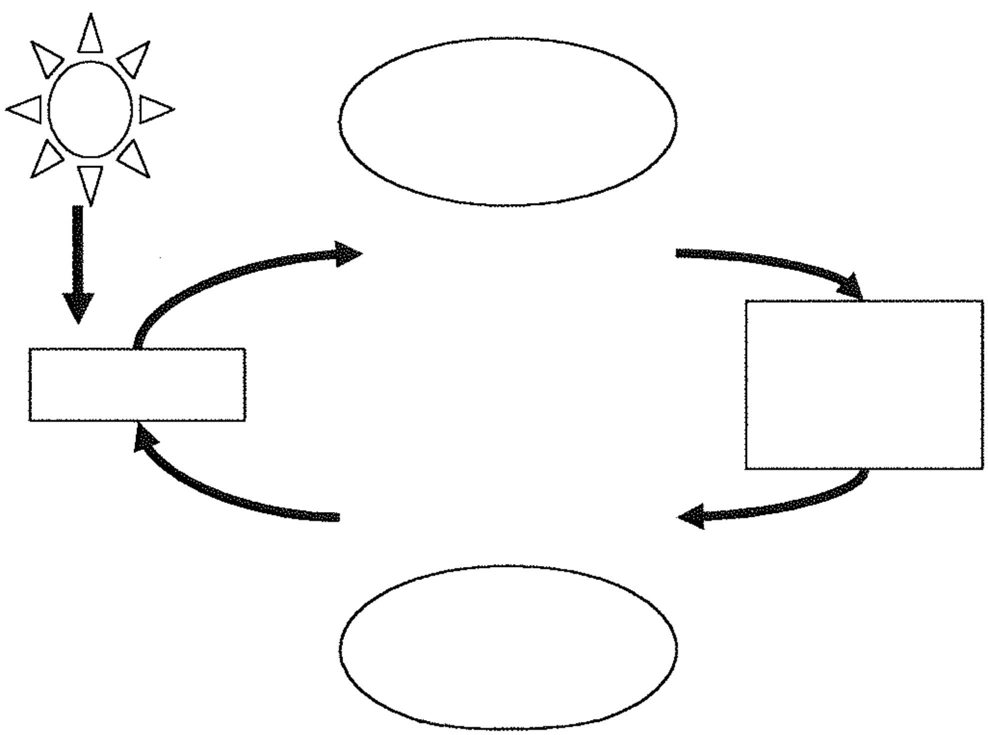
Biology 30 Cellular Processes

I PHOTOSYNTHESIS

- All organisms use energy to carry out the functions of life.
- Some organisms obtain this energy directly from sunlight. They capture part of the energy in light and store it within organic compounds. The process by which this energy transfer takes place is called **photosynthesis**.

A. Energy For Life Processes

- Organisms that manufacture their own food from inorganic substances and energy are **autotrophs**. Most autotrophs use photosynthesis to convert light energy from the sun into chemical energy, which they then store in various organic compounds, primarily carbohydrates
- Organisms, like animals, that cannot manufacture their own organic compounds from inorganic substances are called **heterotrophs**. Heterotrophs obtain food by eating autotrophs or by eating other heterotrophs that feed on autotrophs.
- Photosynthesis involves a complex series of chemical reactions, in which the product of one reaction is consumed in the next reaction. A series of reactions linked in this way is referred to as a **biochemical pathway**
- Autotrophs use the biochemical pathways of photosynthesis to manufacture organic compounds from carbon dioxide (CO_2) and water (H_2O) to create a carbohydrate (CH_2O) and molecular oxygen (O_2) is released.
- Some of the energy stored in organic compounds is released by cells in another set of biochemical pathways, known as **cellular respiration**
- Both autotrophs and heterotrophs perform cellular respiration.
- During cellular respiration in most organism, organic compounds are combined with molecular oxygen O_2 are reactants used in cellular respiration. The waste products of cellular respiration, carbon dioxide and water are reaction used in photosynthesis.



B. Light Absorption In Chloroplasts

- In plants, the initial reactions in photosynthesis are known collectively as the **<u>light reactions</u>**
- They begin with the absorption of light in chloroplasts
- Most chloroplasts are similar in structure of the organism in which they are found.
- Each chloroplast is surrounded by a pair of membranes.
- Inside the inner membrane is another system of membranes, arranged as flattened sacs called **<u>thylakoids</u>** that are interconnected and some are layered on top of one another to form stacks called **<u>grana</u>**.
- Surrounding the thylakoids is a solution called the **<u>stroma</u>**

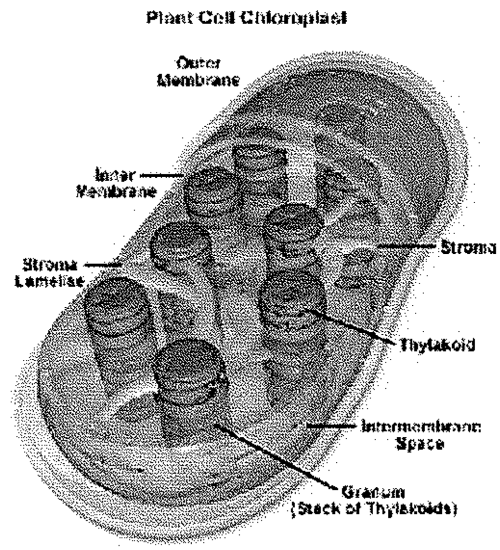
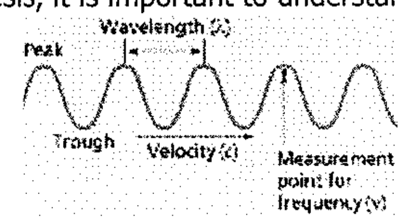


Figure 1

(1) Light and Pigments

- To explain how chloroplasts absorb light in photosynthesis, it is important to understand some of the properties of light
- Light from the sun appears white but is actually composed of a variety of colors known as the **<u>visible spectrum</u>**
- Light travels through space as waves of energy. These waves are measured in terms of their **<u>wavelength</u>**, the distance between crests in a wave.



- When white light strikes an object, its component colours can be reflected, transmitted, or absorbed by the object. However, the various colours will react differently if the object contains a **<u>pigment</u>**, which is a compound that absorbs light. Most pigments absorb certain colours more strongly than others. By absorbing certain colors, a pigment subtracts those colours from the visible spectrum. Therefore, the light that is reflected or transmitted by the pigment no longer appears white but rather the light wave that is being reflected.

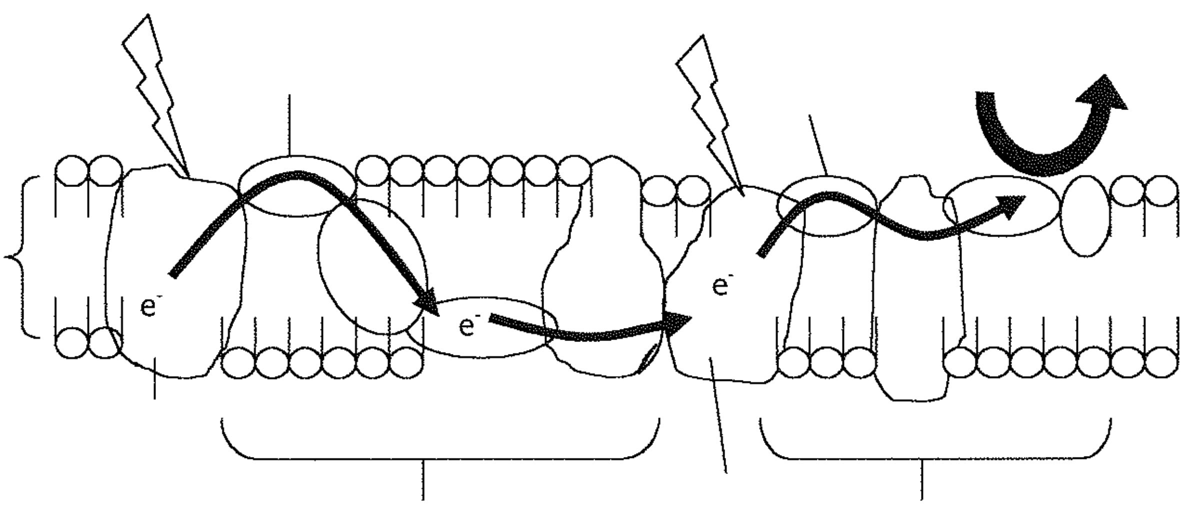
(2) Chloroplast Pigments

- Located in the membrane of the thylakoids are a variety of pigments, the most important of which are called **<u>chlorophylls</u>**. There are several different types. The two most common types are <u>chlorophyll a</u> and <u>chlorophyll b</u>
- A slight difference in molecular structure between the two chlorophylls causes the two molecules to absorb different colours of light.
- Only chlorophyll a is directly involved in the light reactions of photosynthesis.
- Chlorophyll b assists chlorophyll a in capturing light energy, and therefore chlorophyll b is called an **<u>accessory pigment</u>**

- Other compounds found in the thylakoid membrane, include the yellow, orange, and brown **carotenoids**, also function as accessory pigments.
- By absorbing the accessory pigments enable plants to capture more of the energy in light.
- in the leaves of a plant, the chlorophylls are much more abundant and therefore mask the colours of the other pigments. During the fall, many plants lose their chlorophylls, and their leaves take on the rich hues of the carotenoids.

C. Electron Transport
- The chlorophylls and carotenoids are grouped in clusters of a few hundred pigment molecules in the thylakoid membrane
- Each cluster of pigment molecules is referred to as a **photosystem**
- Two types of photosystems are known: **photosystem I** and **photosystem II**
- They are similar in terms of the kinds of pigment they contain, but they have different roles in the light reactions.
- The light reactions begin when accessory pigment molecules in both photosystems absorb light
- By absorbing light, those molecules acquire some of the energy that was carried by the light waves.
- In each photosystem, the acquired energy is passed quickly to other pigment molecules until it reaches a specific pair of chlorophyll a molecules.

The Light Reactions in the Thylakoid Membrane

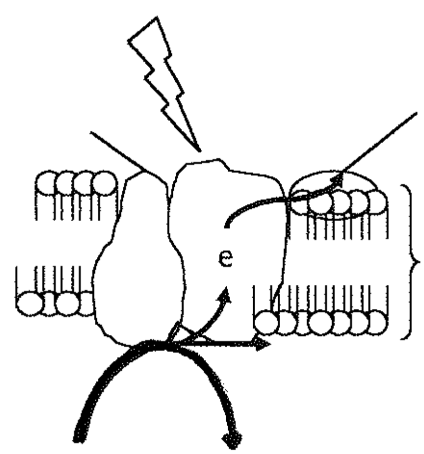


- The events that occur from this point on can be divided into five steps:
  1. Light energy forces electrons to enter a higher energy level in the two chlorophyll a molecules of photosystem II. These energized electrons are said to be 'excited.'
  2. The excited electrons have enough energy to leave the chlorophyll a molecules. Because they have lost electrons, the chlorophyll a molecules have undergone an oxidation reaction. Because an oxidation reaction must be accompanied by a reduction reaction, some substance must accept the electrons that the chlorophyll a molecules have lost. That substance is a molecule in the thylakoid membrane known as the **primary electron acceptor** (PEA)
  3. The primary electron acceptor then donates the electrons to the first of a series of molecules located in the thylakoid membrane. This series of molecules is called an **electron transport chain**, because it transfers electrons from one molecule to the next in series. As the electrons pass from molecule to molecule in the electron transport chain, they lose most of th energy that they acquired when they were excited. The energy they lose is harnessed to move protons into the thylakoid.
  4. At the same time light is absorbed by photosystem II, light is also absorbed by photosystem I. Electrons move from a pair of chlorophyll a molecules in photosystem I to another primary electron acceptor. The electrons that are lost by these chlorophyll a molecules are replaced by the electrons that have passed through the electron transport chain from photosystem II
  5. The primary electron acceptor of photosystem I donates electrons to a different electron transport chain. This chain brings the electrons to the side of the thylakoid membrane that faces the stroma. There the electrons combine with a proton and **$NADP^+$**. $NADP^+$ is an organic molecule that accepts electrons during redox reactions. This causes the $NADP^+$ to become reduced to NADPH.

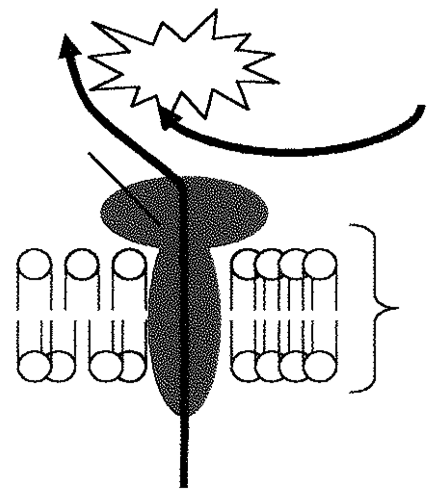
- If the electrons from photosystem II were not replaced, both electron transport chains would stop, and photosynthesis would not occur.
- Water molecules provide the replacement electrons.
- An enzyme inside the thylakoid splits water molecules into protons, electrons, and oxygen.

$$2\,H_2O \rightarrow 4\,H^+ + 4e^- + O_2$$

- For every two molecules of water that are split, four electrons become available to replace those lost by chlorophyll molecules in photosystem II
- The protons that are produced are left inside the thylakoid, while the oxygen diffuses out of the chloroplast and can then leave the plant.
- Thus, oxygen can be regarded as a byproduct of the light reactions - it is not needed for photosynthesis to occur but it is needed for the next cellular process of **cellular respiration**.



D. Chemiosmosis



- An important part of the light reactions is the synthesis of ATP through a process called **chemiosmosis**.
- Chemiosmosis relies on a concentration gradient of protons across the thylakoid membrane.
- Recall some protons are produced from the breakdown of water molecules inside the thylakoid. Other protons are pumped from the stroma to the interior of the thylakoid. The energy required to pump protons is supplied by the excited electrons as they pass along the electron transport chain of photosystem II.
- Both of these mechanisms act to build up a concentration gradient of protons. That is, the concentration of protons is higher inside the thylakoid than in the stroma.
- The concentration gradient of protons represents **potential energy**. A protein called ATP synthase, which is located in the thylakoid membrane, harnesses that energy. ATP synthase makes ATP by adding a phosphate group to **adenosine diphosphate** or **ADP**
- The movement of protons from the inside of the thylakoid to the stroma provides the energy that drives this reaction. Thus, ATP synthase converts the potential energy of the proton concentration gradient into chemical energy stored in ATP.
- ATP is the main energy substance of the cell.
- Together NADPH and ATP provide energy for the second set of reactions in photosynthesis, known as the **Calvin cycle**
- ATP synthase is a multi functional protein. By allowing protons to cross the thylakoid membrane, ATP synthase functions as a carrier protein. By catalyzing the synthesis of ATP from ADP, ATP synthase functions as an **enzyme**, an organic molecule that acts as a catalyst

D. The Calvin Cycle

- The second set of reactions in photosynthesis involves a biochemical pathway known as the **Calvin Cycle**. This pathway produces organic compounds, using the energy stored in ATP and NADPH during the light reactions.
- The Calvin cycle is named after Melvin Calvin (1911 - 1997), the American scientist who worked out the details of the pathway.

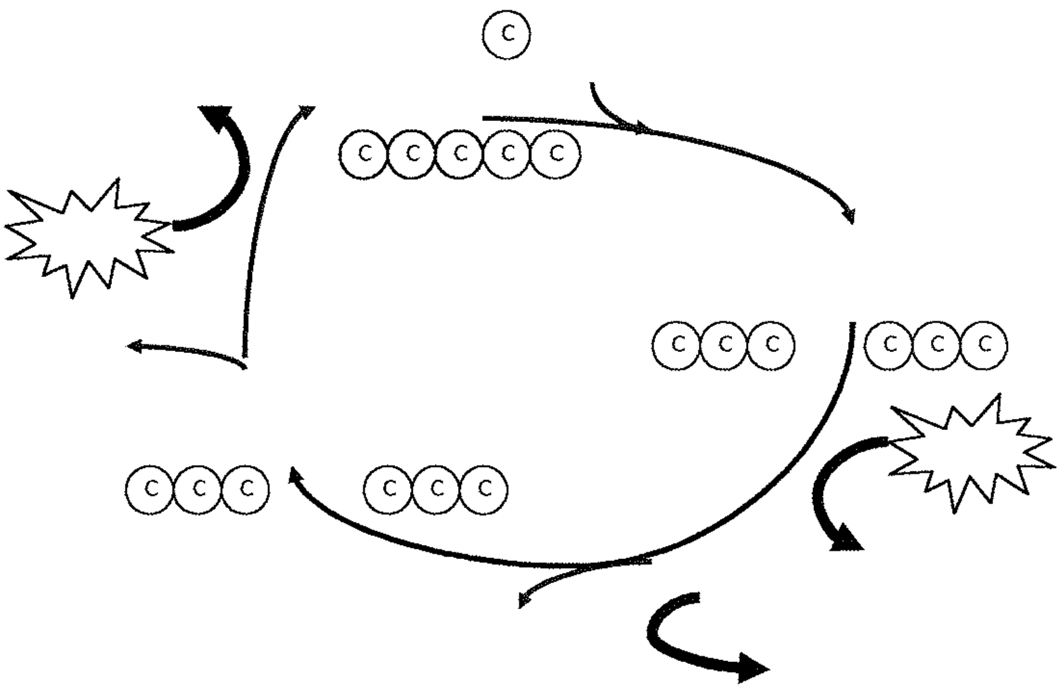
(1) Carbon Fixation by the Calvin Cycle

- In the Calvin cycle, carbon atoms from CO_2 are bonded or "fixed" into organic compounds.
- This incorporation of CO_2 into organic compounds is referred to as **carbon fixation**
- The Calvin cycle has three major steps with occur within the stroma of the chloroplast.

Step 1 - CO_2 diffuses into the stroma from the surrounding cytosol (cytoplasm). An enzyme combines with the CO_2 molecule with a five carbon carbohydrate called **RuBP**. The product is a six-carbon molecule that splits immediately into a pair of three-carbon molecules known as **PGA**

Step 2 - PGA is converted into another three-carbon molecule **PGAL**, in a two-part process. First, each PGA molecule receives a phosphate group from a molecule of ATP. The resulting compound then receives a proton from NADPH and releases a phosphate group, producing PGAL. In addition to PGAL, these reactions produce ADP, $NADP^+$, and phosphate. These three products can be used again in the light reactions to synthesize additional molecules of ATP and NADPH.

Step 3 - Most of the PGAL is converted back into RuBP in a complicated series of reactions. These reactions require a phosphate group from another molecule of ATP, which is changed into ADP. By regenerating the RuBP that was consumed in Step 1, the reactions of Step 3 allow the Calvin cycle to continue operating. However, some PGAL molecules are not converted into RuBP. Instead, they leave the Calvin cycle and can be used by the plant cell to make other organic compounds.



(2) The Balance Sheet for Photosynthesis

- Each turn of the Calvin cycle fixes one carbon dioxide molecule.
- Since PGAL is a three-carbon compound, it takes three turns of the cycle to produce each molecule of PGAL.
- For each turn of the cycle, two ATP molecules and two NADPH molecules are used in Step 2 - one for each molecule of PGAL produced - and one more ATP molecule is used in Step 3. Therefore, three turns of the Calvin cycle use nine molecules of ATP and six molecules of NADPH.
- Some of the PGAL and other molecules made in the Calvin cycle are built up into a variety of organic compounds, including amino acids, lipids, and carbohydrates. Among the carbohydrates are the monosaccharides glucose and fructose, the disaccharide sucrose, and the polysaccharides glycogen, starch, and cellulose.
- Most heterotrophs depend on the chemical energy that is stored in the organic compounds made by plants and other photosynthetic organisms.
- Recall that water split during the light reactions, yielding electrons, protons, and oxygen as a byproduct. Thus, the simplest overall reaction for photosynthesis, including both the light reactions and the Calvin cycle, can be written as follows:

- In the equation above, (CH_2O) represents the general formula for a carbohydrate. It is often replaced in this equation by the carbohydrate glucose, giving the following equation:

- Keep in mind, however, that glucose is not actually produced by the pathways of photosynthesis. Glucose is included in the equation mainly to emphasis the relationship between photosynthesis and cellular respiration.

E. Alternative Pathways

- The Calvin cycle is the most common pathway for carbon fixation.
- Plant species that fix carbon exclusively though the Calvin cycle are known as **C_3 plants** because of the three-carbon compound, PGA, that is initially formed.
- Other plant species fix carbon through alternative pathways and then release it to enter the Calvin cycle.
- These alternative pathways are generally found in plants that evolved in hot, dry climates. Under such conditions, plants can rapidly lose water to the air. Most of the water loss from a plant occurs through small pores called **stomata**, which are usually located on the undersurface of leaves.
- Stomata are also the major passageways through which carbon dioxide enters and oxygen leaves a plant. Thus, when a plant's stomata are partly closed, the level of carbon dioxide in the plant falls as carbon dioxide is consumed in the Calvin cycle. At the same time, the level of oxygen in the plant rises as the light reactions split water and generate oxygen.

- Both of these conditions - a low carbon dioxide level and a high oxygen level - inhibit carbon fixation by the Calvin cycle.
- Plants with alternative pathways for carbon fixation have evolved ways of dealing with this problem

(a) The C_4 Pathway

- One alternative pathway enables certain plants to fix carbon dioxide into four-carbon compounds. This pathway is therefore called the **C_4 pathway**, and plants that use it are known as C_4 plants.
- During the hottest part of the day, C_4 plants have their stomata partially closed.
- However, certain cells in C_4 plants have an enzyme that can fix CO_2 into four-carbon compounds even when the CO_2 level is low and the O_2 level is high.
- These compounds are then transported to other cells, where CO_2 is released and enters the Calvin cycle.
- C_4 plants include corn, sugar cane, and crabgrass.
- Such plants lose only about half as much water as C_3 plants when producing the same amount of carbohydrate.

(b) The CAM Pathway

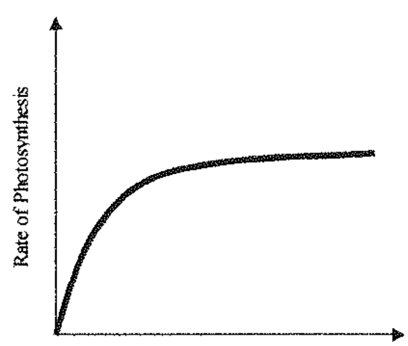
- Cactuses, pineapples, and certain other plants have a different adaptation to hot, dry climates. Such plants fix carbon through a pathway called **CAM**.
- Plants that use the CAM pathway open their stomata at night and close them during the day - just the opposite of what other plants do.
- At night, CAM plants take in CO_2 and fix it into a variety of organic compounds.
- During the day, CO_2 is released from these compounds and enters the Calvin cycle.
- Because CAM plants have their stomata open at night, when the temperature is lower, they grow fairly slowly. However, they lose less water than either C_3 or C_4 plants.

F. Rate of Photosynthesis

- The rate at which a plant can carry out photosynthesis is affected by the plant's environment.
- There are three major factors affecting photosynthesis:

(a) Light Intensity

- One of the most important environment influences is light intensity.
- As light intensity increase, the rate of photosynthesis initially increases and then levels off to a plateau.
- This plateau represents the maximum rate of photosynthesis.
- Higher light intensity cause more electrons in the chlorophyll molecules of both photosystems to become excited.
- As more electrons are excited, the light reactions occur more rapidly.
- At some light intensity, however, all of the available electrons are excited, and any further increase in light intensity will not increase the rate of photosynthesis.



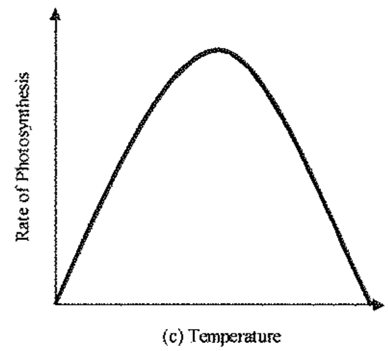
(a) Light Intensity

(b) CO_2 Concentration

- CO_2 is another important influence on photosynthesis.
- Like increasing light intensity, increasing levels of CO_2 around a plant stimulate photosynthesis until the rate of photosynthesis reaches a plateau.
- So a graph similar to light intensity would result.

(c) Temperature

- Raising the temperature accelerates the various chemical reaction involved in photosynthesis.
- As a result, the rate of photosynthesis increases as temperature increase, over a certain range.
- The rate of photosynthesis generally peaks at a certain temperature.
- At that temperature, many of the enzymes that catalyze the reactions in photosynthesis start to become unstable and ineffective.
- Also, the stomata begin to close, limiting water loss and CO_2 entry into the leaves.
- These conditions cause the rate of photosynthesis to decrease when the temperature is further increased.



Biology 30 -- Photosynthesis Review

1. What is the term for the ability to perform work? ______________________.
2. Animals that cannot make their own food are called ________________________.
3. Most organisms use an energy storage molecule called ______________________ ______________________ or simply (______).
4. Light of different wavelengths is different in __________________ and __________________.
5. During photosynthesis, a Reduction Reaction _________ ______________ to a molecule.
6. Oxidation is a process that makes a molecule __________________ electrons.
7. Disk-shaped structures with photosynthetic pigments are known as __________________.
8. The process by which autothrophs convert sunlight into energy is called ______________________.
9. A molecule that can absorb certain light wavelengths and reflect others is a ____________________________.
10. What are the most common group of photosynthetic pigments in plants? ______________________
11. Stroma are gel-like matrix (a solution) that surrounds the ____________________.
12. Photosynthesis occurs in three stages called:
   A.____
   B.____
   C.____
13. Plants that use only the Calvin Cycle for photosynthesis are called ______________.
14. CAM Plants can survive in dry, hot deserts because they can fix carbon at ______________________.
15. What substances do Autotrophs or producers use to make food?
   A.________________________________
   B.________________________________
   C.________________________________
16. The addition of an electron to an atom or a molecule is called ________________.
17. The loss of an electron to an atom or a molecule is called ___________________.
18. Organisms that CAN produce their own food are called ______________________.
19. An important waste product of photosynthesis is ______________________.
20. Photosynthesis occurs in what organelle of plants and algae? ____________________.
21. The Thylakoids are surrounded by a gel-like matrix (solution) called ______________.
22. An object that absorbs all colors appears ____________________.
23. What are the light collecting units of the Chloroplast? _________________.
24. Carbon fixing reactions occur in a pathway called the ______________________ ______________.
25. Chlorophyll reflects and transmits what color? ______________________.
26. An object that reflects all colors appears ________________________.

27. Folded Thylakoids that resemble stacks of pancakes are called

________________________________.

28.The pigments that absorb violet, blue and red light. ______________________

29.The Enzyme that adds a phosphate group to ADP. ________ ______________ to form ____________.

30. What do we call the component colors of white light? ______________________

____

31. What clusters of pigments are called. ______________________

32. A five-carbon carbohydrate in the Calvin cycle. ______________________

33. A three-carbon molecule in the Calvin cycle.______________________

34. A Series of linked chemical reactions is called a ______________________

______________________.

35. The pigments that absorb blue and green light are called

______________________.

36. The oxygen atoms in the oxygen gas produced in photosynthesis come from

______________ ______________________.

37. Both C4 and C3 plants use the ______________ ______________ for carbon fixation.

38. Where does the energy required for the Calvin cycle originate? From ____________ and ______________ produced by the ______________

______________.

39. Protons are move into the thylakoid using energy from ______________ in the

______________ ______________.

40. At the end of photosystem I transport chain, electrons combine with ____________ to form ______________.

41. Carbon atoms are fixed into organic compounds in the ______________

______________.

42. To produce the same amount of carbohydrate, C4 plants require less ______________ ______________ than C3 plants.

43. Where in the chloroplast do the light reactions occur? ______________

44. Where in the chloroplast do the reactions of the Calvin cycle occur?

____

45. What product of the light reactions of photosynthesis is released and does not participate further in photosynthesis? ______________________

46.Which environmental factor will cause a rapid decline in the photosynthesis rate if the factor rises above a certain level? ______________________

47. Accessory pigments differ from chlorophyll a in that they are ____________ directly involved in the ______________ ______________ of photosynthesis.

48. What structure that is found in the thylakoid membrane is important to chemiosmosis? ______________________.

49. Describe the internal structure and external structure of a chloroplast.

50. Explain what happens to the components of water molecules that are split during the light reactions of photosynthesis? (HINT: Name the three products that are produced

when water molecules are split during the light reactions and explain what each product is used for.)

51. Explain the difference between the roles of photosystem I and photosystem II in photosynthesis?

52. Explain why the leaves of some plants look green during the summer then turn yellow, orange, red, or brown during the fall?

53. What plant structures control the passage of water out of a plant and carbon dioxide into a plant? Explain how they control the passage of water out of a plant and carbon dioxide into a plant.

54. What happens to the electrons that are lost by photosystem II? What happens to the electrons that are lost by photosystem I?

55. Photosynthesis is said to be "Saturated" at a certain level of CO2. Explain what this means?

56. Explain how is ATP synthesized in photosynthesis? What is this process called?

57. What is the fate of most of the PGAL molecules in the third step of the Calvin cycle and Why is this important? What happens to the remaining PGAL molecules? What organic compound can be made from PGAL?

58. Explain how CAM plants differ from C3 and C4 plants? How does this difference allow CAM plants to exist in hot, dry conditions?

59. Define biochemical pathway and explain how the Calvin cycle is an example of a biochemical pathway. In what part of the chloroplasts does the Calvin cycle take place?

60. Explain how the function of the chloroplasts is related to its structure.

61. What roles do water molecules play in photosynthesis?

62. Describe the structure and function of the thylakoids of a chloroplasts.

63. What role do accessory pigments play in photosynthesis?