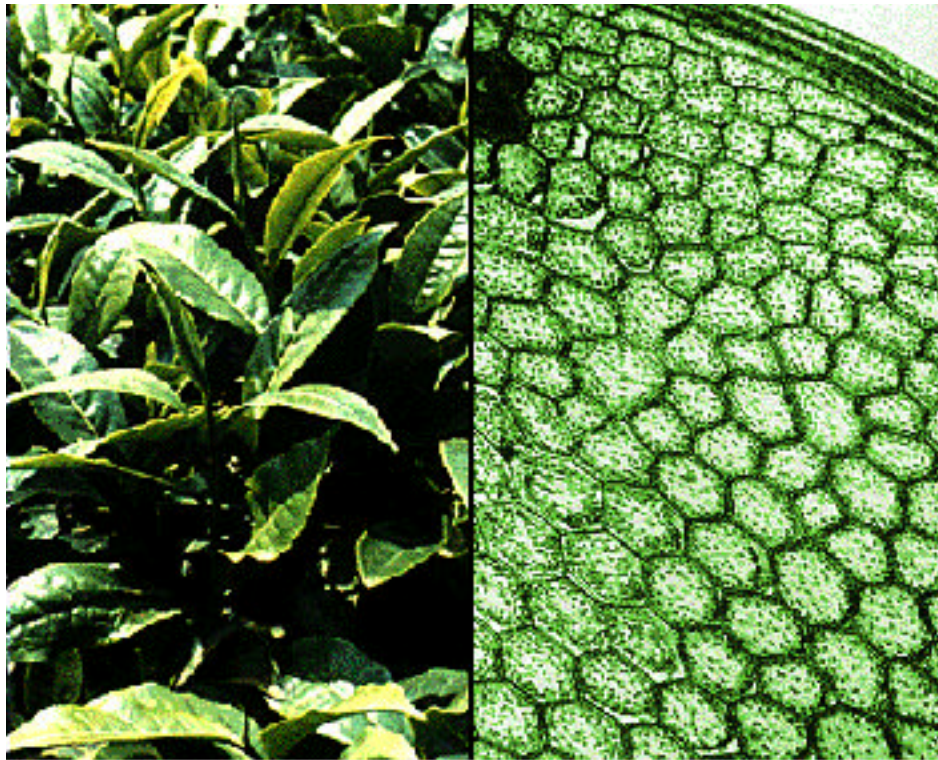


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**Photosynthesis**  
**Program Supplement**



## Photosynthesis TEACHING OBJECTIVES

The following subject areas are illustrated throughout the *Interactive Biology* Multimedia Courseware program, *Photosynthesis*. Ideally, these areas would be augmented with additional course work outside of this program. (*Click on a subject to jump ahead.*)

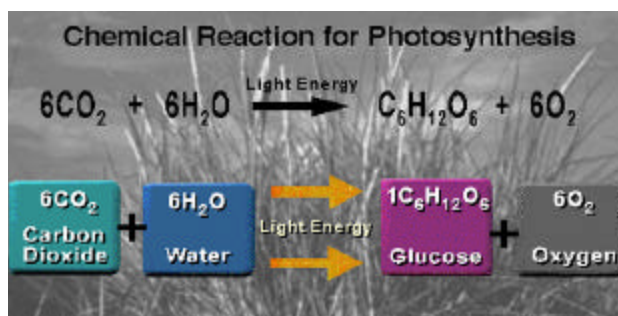
- **An Overview of Photosynthesis:** Including the importance of plants, the raw materials used in photosynthesis, the products of photosynthesis, and how plants shaped the earth's atmosphere.
- **Characteristics of Light:** Including wavelength, photons, and the visible spectrum.
- **Chloroplast Structure And The Arrangement Of Pigments Into Photosystems.**
- **Photosynthetic Pigments:** Including chlorophyll *a*, chlorophyll *b*, and the carotenoids.
- **The Light Reactions:** Including the role of water, cyclic versus non-cyclic electron flow, the role of the proton gradient and ATP synthase in generating ATP, and the role of NADP<sup>+</sup> reductase in generating NADPH.
- **The Dark Reactions:** Including the Calvin Cycle, the importance of CO<sub>2</sub>, the role of energy providing molecules produced in the light reactions, the formation of PGAL and glucose, and the reformation of RuBP.

## Study Guide #1 PLANTS AND PHOTOSYNTHESIS

The plants you see around your town, as well as those growing in the expansive rain forests of the tropics, are vitally important to life on earth. Throughout the day, plants absorb light energy from the sun and use this energy to produce organic molecules. While making these molecules, plants also give off the oxygen that allows much of earth's life to flourish. The process by which plants do this is known as photosynthesis.

Plants require three things to carry out photosynthesis. First of all, plants need light. This light can be provided by an artificial source, such as a growth lamp, but is most often provided by the sun. Secondly, plants need two chemical compounds: water (H<sub>2</sub>O) and carbon dioxide (CO<sub>2</sub>).

In photosynthesis, plants absorb energy from the sun. This energy is in the form of light. Through a series of chemical reactions, this light energy is converted into chemical bond energy. This chemical bond energy is most frequently stored in the sugar molecule known as glucose. Glucose is in turn used later as an energy source for the plant to grow and reproduce. Water and carbon dioxide are required at various stages in photosynthesis. These two compounds provide electrons, hydrogen ions, and carbon atoms that the plants need to make glucose. Along the way, oxygen (O<sub>2</sub>) is given off as a waste product.



Earth's early atmosphere had very little oxygen in it. Only after plants and other photosynthetic organisms came along were oxygen requiring creatures - such as humans, fish, dinosaurs, and insects - able to exist. It is difficult to imagine how the diversity of animal life we see on earth today could have evolved in a world without the oxygen provided by photosynthesis.

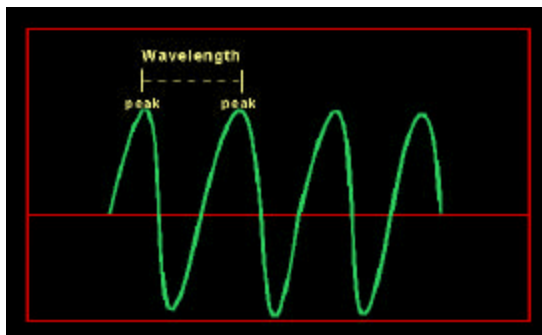
Photosynthetic organisms provide not only oxygen, but a key link in the food chain as well. Without photosynthesis, there could be no plants and algae. Obviously then, there would be no organisms that feed on plants or algae.

## Study Guide #2 CHARACTERISTICS OF LIGHT

Light has some unique properties; let's take a closer look.

At times, light exists as a wave. Much like waves on the ocean, light waves have peaks and troughs. The distance from one peak to the next is known as the wavelength. The total wavelengths that are possible for light (from the shortest to the longest) are known as the spectrum.

There are many different wavelengths of light that the eye can detect. Together, these wavelengths make up the visible light spectrum. Different wavelengths correspond to different colors in the spectrum. For instance violet has a very short wavelength. This is the smallest wavelength discernible by the human eye. Red, on the other hand, has a very long wavelength. This is the longest wavelength discernible by the human eye. All other colors the human eye can detect have wavelengths that lie between violet and red. Sunlight, which appears to be white until passed through a prism, is a blend of all wavelengths of light. Not all light is visible to our eyes. X-rays are light waves with wavelengths too short for the human eye to detect and radio waves, although converted to sound waves in stereo equipment, are light waves with wavelengths too long for the human eye to detect.

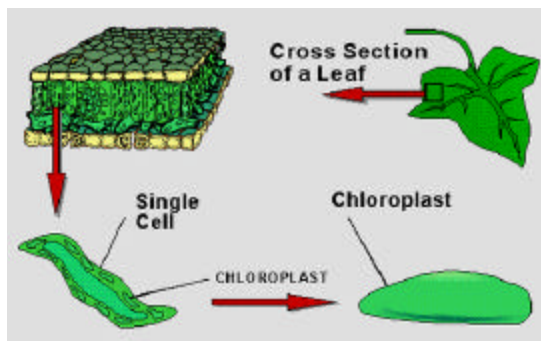


Although light can exist and travel as a wave, it can also exist as a particle. These particles of light energy are known as photons.

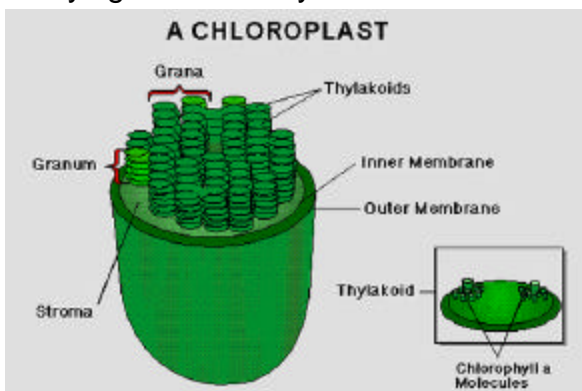
### Study Guide #3 CHLOROPLASTS AND PIGMENTS

To absorb light, plants use highly specialized structures or organelles known as chloroplasts. These organelles are dispersed throughout much of the plant surface and are the organelles in which photosynthesis takes place.

A double membrane surrounds chloroplasts. Inside of chloroplasts are disc-like structures called thylakoids. These thylakoids are stacked one on top of the other. Surrounding the thylakoids are intricate thylakoid membranes. Inside of the thylakoid membrane is the thylakoid compartment. A stack of thylakoids is called a granum and several stacks of thylakoids are called grana. Within the chloroplast and surrounding the grana is a thick solution called the stroma.



Lying within the thylakoid membrane are pigments. Pigments are molecules that absorb specific wavelengths of light. Wavelengths that pigments are not able to absorb are reflected instead. Chlorophyll *a* is a pigment commonly found in plants. It can absorb violet, blue, and red wavelengths of light, but cannot absorb green wavelengths. What happens to the wavelengths of green light? They are reflected. This reflected green light is picked up by your eye when you look at, for example, grass. This is why grass looks green in color.

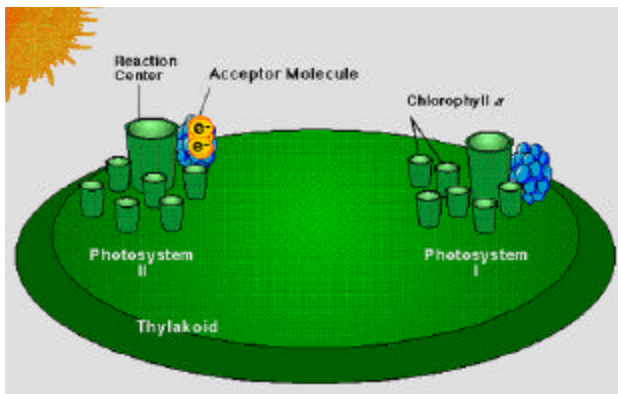
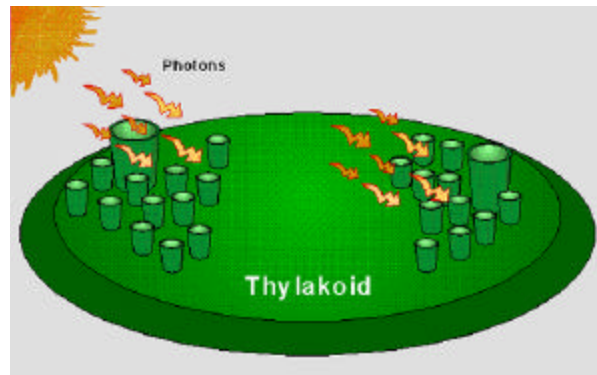


Other pigments that are common in leaves are chlorophyll *b*, which absorbs light at wavelengths similar to chlorophyll *a*, and carotenoids. Carotenoids cannot absorb yellow or orange light, and these pigments give foliage its distinctive fall colors. Although chlorophyll *b* and the carotenoids are able to absorb light, they must work in conjunction with chlorophyll *a*. For the plant to use any light absorbed by these two pigments, the light energy must first be passed along to chlorophyll *a*. For this reason, chlorophyll *a* is considered to be the main photosynthetic pigment. By having more than one type of pigment, plants are better able to harvest the light that reaches them.

## Study Guide #4 LIGHT ABSORPTION BY PIGMENTS

Within each thylakoid membrane, are groups of pigments. Each group is called an antenna assembly, and is composed of several hundred pigments that are linked together.

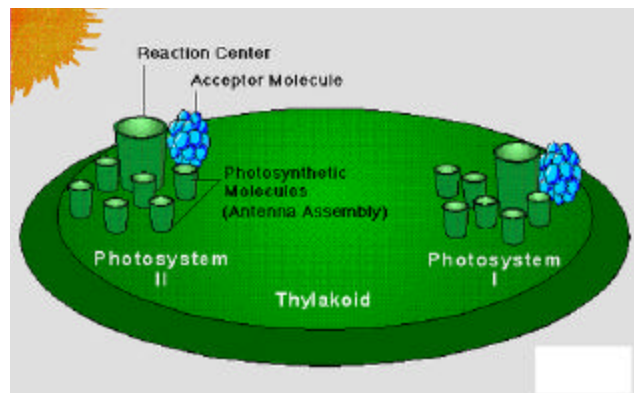
All of the pigments in this antenna assembly are able to absorb photons of light. Remember though, if chlorophyll *b* or the carotenoids absorb a photon, the energy is transferred to a chlorophyll *a* molecule.



When chlorophyll *a* molecules absorb photons, the molecules become excited. In this excited state, chlorophyll *a* molecules are able to release electrons. These electrons are passed along the chlorophyll *a* molecules within the antenna assembly until they reach a special chlorophyll molecule known as the reaction center. As electrons bombard the reaction

center, it in turn passes electrons to an acceptor molecule. The name biologists have given to an antenna assembly, reaction center, and acceptor molecule is a Photosystem.

There are two Photosystems involved in photosynthesis. These have been creatively named Photosystem I and Photosystem II. Both of these thylakoid-bound photosystems work in conjunction during the first series of reactions in photosynthesis. This series of reactions is known as the light reactions.



## Study Guide #5 THE LIGHT REACTIONS

Now that you know a little about the structures involved in photosynthesis, its time to take a closer look at these reactions. The overall chemical reaction involved is:



During photosynthesis, plants combine 6 molecules of carbon dioxide, 6 molecules of water, and energy from the sun to produce one molecule of glucose ( $\text{C}_6 \text{H}_{12} \text{O}_6$ ) and 6 molecules of oxygen. This occurs in a series of reactions taking place in different locations within the chloroplast.

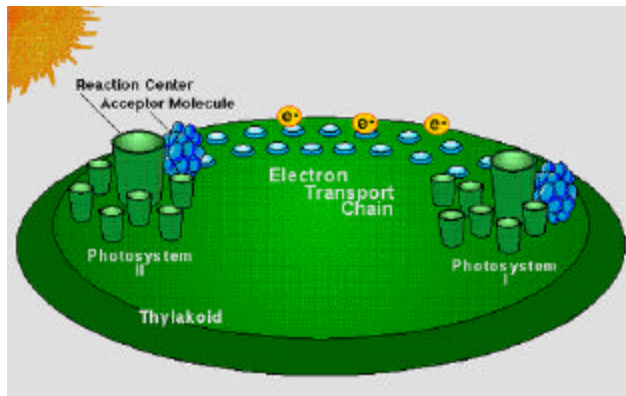
The first stage of photosynthesis is a series of reactions, known as the light reactions, that takes its name from the fact that light is required. The products of the light reactions are ATP, NADPH, and oxygen. ATP and NADPH are special, energy-storing molecules. The energy stored in these molecules is later used to make glucose, which is the molecule plants use for long term energy storage. Let's take a closer look at the light reactions.

The first step in the light reactions is the absorption of a photon by Photosystem II. When a pigment in this photosystem is struck by light of the correct wavelength, it absorbs the photon and becomes excited. In this excited state, the pigment gives up an electron

which moves along a series of chlorophyll *a* molecules until reaching the reaction center. The reaction center in turn becomes excited and releases its own electrons to the acceptor molecule. Once reaching the acceptor molecule, the electrons leave Photosystem II. Where do these electrons go?

Photosystem II needs to replace all of the electrons leaving, or it would very quickly run out of electrons. This is where water enters the picture. For each pair of electrons Photosystem II loses, a water molecule is split. In the process, two electrons are stripped from water and move to the reaction center. These electrons from water replace the pair of electrons the photosystem lost. After water is split into hydrogen and oxygen, two oxygen atoms combine to form  $\text{O}_2$  (it is in this form that oxygen is used by animals). The oxygen is then released into the atmosphere. The plant uses the hydrogen ions in a later stage of photosynthesis.

From the acceptor molecule, electrons enter an electron transport chain. This electron transport chain, or ETC for short, is located on the thylakoid membrane and connects Photosystem II to Photosystem I. As the electrons slide along the ETC from Photosystem II to Photosystem I, they lose energy. This energy given up by the electrons is stored in ATP molecules. We'll cover how this is accomplished a little later.

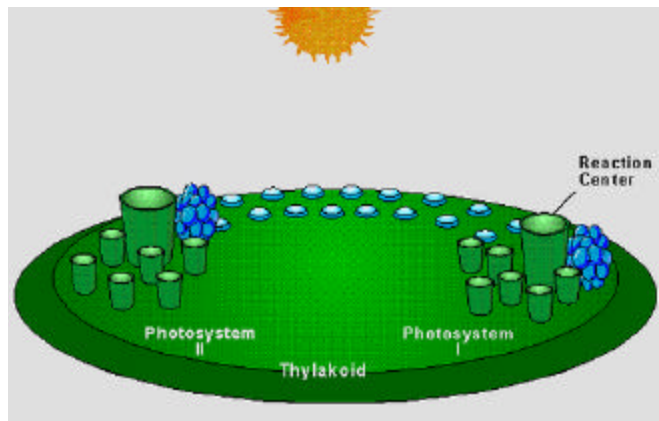




## Study Guide #6 THE LIGHT REACTIONS

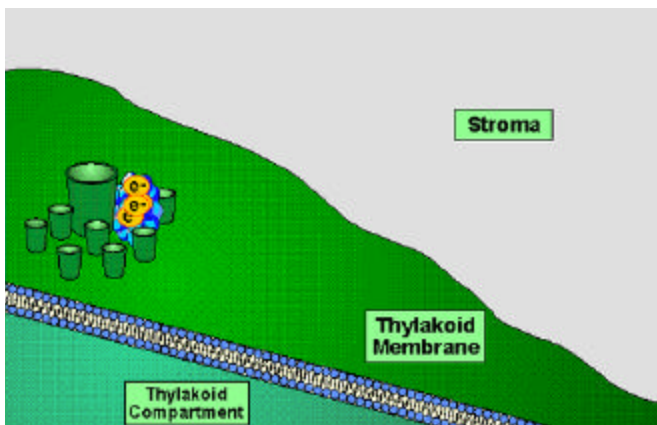
### Photosystem I and Cyclic versus Non-Cyclic Electron Flow

Photosystem I, like Photosystem II, is able to absorb light. When sunlight is available, excited electrons are constantly passed from chlorophyll a molecules, to the reaction center, and ultimately to the acceptor molecule for Photosystem I. The electrons leaving Photosystem I are replenished by the steady stream electrons coming into the system from Photosystem II.



From the acceptor molecule, electrons leaving Photosystem I can follow one of two paths. These paths are known as cyclic electron flow and non-cyclic electron flow.

In cyclic electron flow, electrons begin at the acceptor molecule and are passed to an electron transport chain.



This ETC, like the one connecting the two Photosystems, is a series of receptor molecules able to pass along electrons. Unlike the ETC you learned of earlier however, the one involved in cyclic electron flow leads directly back to Photosystem I. These electrons begin at the acceptor molecule for Photosystem I and wind up back at Photosystem I again. As the

electrons slide along this chain of receptor molecules in cyclic electron flow, they lose energy. This energy is in turn stored in ATP molecules. Energy from the electrons involved in cyclic electron flow is used to produce ATP.

In non-cyclic electron flow, electrons begin at the acceptor molecule and are once again passed to an electron transport chain. This series of receptor molecules, however, leads directly to an enzyme known as NADP<sup>+</sup> reductase. Once at this enzyme, the electrons are passed to a molecule of NADP<sup>+</sup>, otherwise known as nicotinamide adenine dinucleotide phosphate. This NADP<sup>+</sup> molecule then quickly picks up a hydrogen ion (a proton, or H<sup>+</sup>) and becomes NADPH.

NADPH is able to store electrons at a high state of energy for later use. Electrons involved in non-cyclic electron flow are used in the generation of NADPH.

So let's recap what has taken place in the light reactions. Light strikes and is absorbed by Photosystem II. This excites electrons which are passed to the reaction center and then to the acceptor molecule. Water is split to replace these electrons lost by Photosystem II and oxygen is given off. The electrons pass along an ETC to Photosystem I. As they move along this ETC, ATP is produced (more on this soon, I promise). Photosystem I can also absorb light, and send excited electrons to its acceptor molecule. Electrons leaving Photosystem I are replaced by the electrons arriving from Photosystem II. Electrons exiting Photosystem I can travel along two distinct paths. Cyclic electron flow returns electrons back to Photosystem I and results in the production of ATP. Non-cyclic electron flow delivers electrons to the enzyme NADP<sup>+</sup> reductase that in turn delivers them to NADPH molecules. NADPH stores high-energy electrons for later use. The big picture then: electrons flow in a constant stream from water molecules to NADPH molecules, generating ATP as they go.

In the next study guide, we'll look at how ATP is generated.

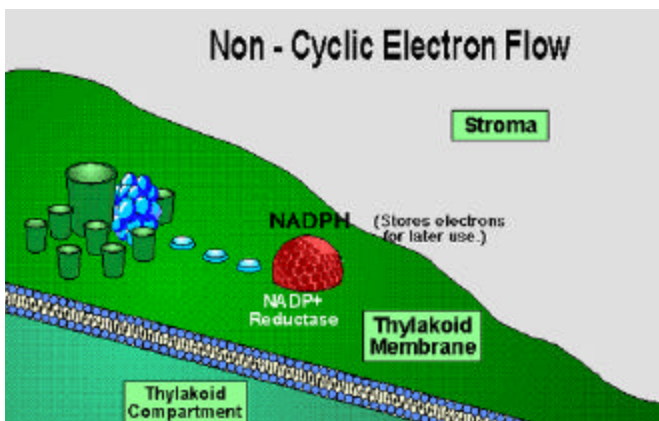
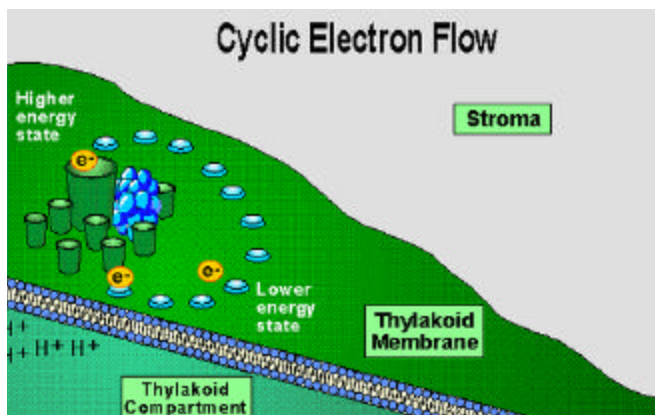
## Study Guide #7

### ATP GENERATION AND PROTON GRADIENT

ATP (a high energy molecule) is produced at two points during the light reactions: while electrons are moving along the ETC connecting Photosystem II to Photosystem I, and during cyclic electron flow.

While electrons are moving along these two paths, some of their energy is harnessed and used to move hydrogen ions across the thylakoid membrane. These hydrogen ions, otherwise known as protons, are pumped from the stroma into the thylakoid compartment. This results in a proton gradient, with more protons on the inside of the thylakoid compartment than on the outside.

Protons want to move back into the stroma, but can only pass through the thylakoid membrane in specific locations. The protons must pass through a very specialized enzyme known as ATP synthase.



ATP synthase is a tunnel shaped enzyme that spans the thylakoid membrane. In a very orderly manner, protons exit the thylakoid compartment through the passage provided by this enzyme. ATP synthase converts ADP (a low energy molecule) into ATP (a molecule containing one very high energy bond). On the stroma side of the membrane, this enzyme adds an inorganic phosphate

group to ADP molecules. With the addition of this phosphate group, ADP becomes ATP. The energy needed to accomplish this is provided by the passage of protons through ATP synthase. It is important to note one thing: electrons sliding along the ETC are not transferred to ATP. Electrons are only transferred to NADP+ molecules. Electrons moving along the ETC and involved in cyclic electron flow provide the energy to pump protons across the thylakoid membrane, nothing more.

It is now time for a review. Electrons passing from Photosystem II to Photosystem I, and electrons involved in cyclic electron flow, provide energy to pump protons from the stroma into the thylakoid compartment. This establishes a proton

gradient, with a higher concentration of protons inside of the thylakoid than is found outside of the thylakoid. These protons want to move back into the stroma, but to do so must pass through the enzyme ATP synthase. As they pass through this enzyme, their energy is used to add an inorganic phosphate group to an ADP molecule. With the addition of the phosphate group, ADP becomes ATP. The bond linking this extra phosphate group is very high in energy, and this energy is used at later stages in photosynthesis.

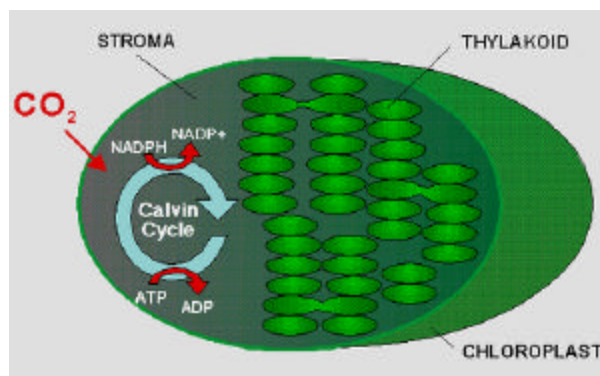
## Study Guide #8 THE DARK REACTIONS

Now that you know how light energy is used to generate ATP and NADPH, and how water is split to provide electrons and produce oxygen, it's time to take a look at the second stage of photosynthesis. This stage of photosynthesis is named the dark reactions because no light is required for them to proceed.

During the dark reactions, energy rich ATP and NADPH molecules produced earlier are used to help convert carbon dioxide ( $\text{CO}_2$ ) into organic molecules needed by the plant, such as glucose. This involves a very complex series of reactions known as the Calvin Cycle. Let's take a closer look.

Glucose is a sugar molecule containing 6 carbon atoms.  $\text{CO}_2$ , the compound used to form glucose, contains only one carbon atom. Therefore, six molecules of carbon dioxide must come into the Calvin Cycle to make a single glucose molecule. For this reason, we'll follow the path of 6  $\text{CO}_2$  molecules at once.

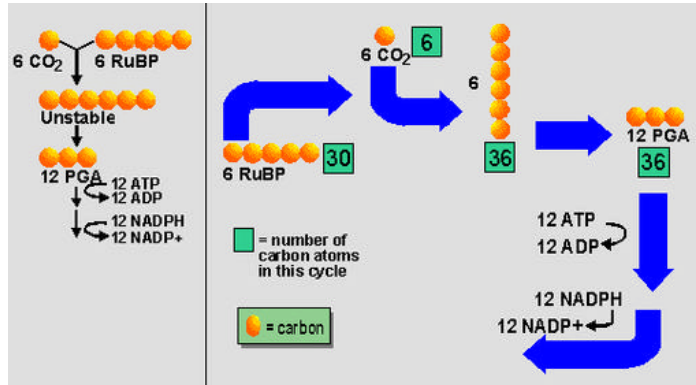
Carbon dioxide from the atmosphere enters plant cells and then diffuses into the stroma of chloroplasts. There, it is brought into the Calvin Cycle. The first step in this cycle is the combination of 6  $\text{CO}_2$  molecules with 6 molecules of a compound known as ribulose biphosphate, or RuBP for short. These new compounds are unstable, and quickly break in half, forming 12 molecules of a stable, 3 carbon-containing compound.



These 12 molecules now undergo a series of reactions fueled by the ATP and NADPH produced earlier. At the end of these reactions, 12 molecules of a compound known as phosphoglyceraldehyde (PGAL) are formed.

PGAL is a very important compound in the Calvin Cycle. This is the compound used to make glucose. Two molecules of PGAL (which, once again, contains 3 carbon atoms) are combined to make one molecule of glucose (which contains 6 carbon atoms).

Glucose contains six carbon atoms. Do you remember how many  $\text{CO}_2$  molecules entered the cycle at the start? Six  $\text{CO}_2$  molecules entered the Calvin Cycle. These 6  $\text{CO}_2$  molecules contributed a total of six carbon atoms to the Calvin Cycle. The 6 carbon dioxide molecules that entered the cycle provided the carbon atoms that eventually became glucose.



The plant has now converted 6 molecules of CO<sub>2</sub> into one molecule of glucose. The plant used two molecules of PGAL in doing so, and we are still left with 10 additional molecules of PGAL.

The plant has just made one molecule of glucose without using a single carbon

atom of its own (remember, these carbon atoms came from CO<sub>2</sub>, which is readily available in the atmosphere). The plant therefore has exactly the same number of carbon atoms it had to begin with, but these are in the form of PGAL and the cycle started out with the compound RuBP.

Using the ATP and NADPH made earlier, the plant converts these 10 molecules of PGAL into 6 molecules of RuBP. These 6 RuBP molecules are then able to react with 6 molecules of CO<sub>2</sub> and start the cycle once more. In this way, plants are able to continuously recycle and combine their own carbon-containing molecules with CO<sub>2</sub> to make glucose.

## Study Guide #9 REVIEW OF PHOTOSYNTHESIS

Plants harvest energy from the sun. This energy arrives in the form of light. Light has wave-like properties. Like any other wave, light waves can be measured. The distance from one peak in the light wave to the next peak is known as the wavelength. Light also has particle-like properties. A particle of light is known as a photon. Light that can be detected by the human eye makes up the visible spectrum. White light, which can be separated by a prism, is made up of all colors of light.

In a process known as photosynthesis, plants convert light energy into energy stored in the chemical bonds of certain molecules. ATP and NADPH are short-term energy storing molecules. Glucose and other organic compounds are long term energy storing molecule produced during photosynthesis.

Photosynthesis takes place in organelles known as chloroplasts. Within chloroplasts are disc-like structures known as thylakoids. The chemical reactions of photosynthesis take place on the thylakoid membrane. A stack of thylakoids is called a grannum. Several stacks are referred to as granna. Within the chloroplast and surrounding the thylakoids is a dense fluid called stroma. Embedded within the thylakoid membrane are special molecules known as pigments. Pigment molecules are able to absorb light of a certain wavelength. Light of a wavelength not absorbable by the pigment is reflected. Common pigments are chlorophyll *a*, chlorophyll *b*, and the carotenoids.

Pigments are arranged ingroups called antenna assemblies. An antenna assembly, its reaction center, and acceptor molecule make up a photosynthetic unit known a photosystem. There are two photosystems involved in photosynthesis: Photosystem I and Photosystem II are involved in the first series of reactions in photosynthesis called the light reactions. These reactions only take place in the presence of light.

Plant pigments in the antenna assembly of Photosystem II absorb light of the right wavelength. This excites their electrons. These electrons are passed along chlorophyll **a** molecules until reaching the reaction center. The reaction center in turn passes the electrons to an acceptor molecule, which shuttles the electrons into an electron transport chain leading to Photosystem I. Electrons leaving Photosystem II are replaced when water molecules are split. When water is split, two oxygen atoms combine to form molecular oxygen (O<sub>2</sub>, the form we breathe).

As the electrons leaving Photosystem II slide along the ETC, they provide energy to pump protons (hydrogen ions, H<sup>+</sup>) into the thylakoid compartment. This generates a proton gradient. Protons leaving the thylakoid compartment pass

through the enzyme ATP synthase that converts ADP into ATP on the stroma side of the thylakoid.

Pigments in photosystem I can also be excited by absorbing light. These pigments release electrons which can follow one of two paths once reaching the acceptor molecule. These paths are known as cyclic electron flow and non-cyclic electron flow.

During cyclic electron flow, electrons leave the acceptor molecule and follow a chain of receptor molecules that leads directly back to Photosystem I. Electrons involved in cyclic electron flow provide energy to pump protons into the thylakoid compartment.

During non-cyclic electron flow, electrons leaving Photosystem I are sent to an enzyme known as NADP<sup>+</sup> reductase. This enzyme passes the electrons onto the electron-storing molecule NADPH. Electrons leaving Photosystem I are replaced by the electrons arriving from Photosystem II. In the light reactions then, electrons flow in a continuous circuit from water to NADPH.

The second series of reactions in photosynthesis are known as the dark reactions. In the dark reactions, the high-energy molecules ATP and NADPH are used to fuel the production of glucose. These reactions are commonly referred to as the Calvin Cycle.

The first step in the Calvin Cycle involves the reaction of carbon dioxide (CO<sub>2</sub>) with the compound RuBP. This results in an unstable compound that quickly splits in half to form a stable, three-carbon containing compound. This compound undergoes a series of reactions fueled by ATP and NADPH, and the molecule PGAL are formed.

Two PGAL molecules (each containing 3 carbon atoms) combine to form one molecule of glucose (containing 6 carbon atoms), which is used as a long term energy storage molecule in plants. Most PGAL, however, is converted back into RuBP. Once again, the ATP and NADPH made during the light reactions provide the energy. This newly formed RuBP is able to react with CO<sub>2</sub> and begin the Calvin Cycle once more.



## **Photosynthesis QUIZ PACK**

The following quizzes are meant to test student understanding of specific topic areas covered in the Interactive Biology Multimedia program, *Photosynthesis*. Many, but not all, of these questions have been addressed directly in the study guides designed to strengthen student understanding of these topics.

**Quiz #1**  
**PLANTS AND PHOTOSYNTHESIS**

1. Photosynthetic organisms such as plants and algae make very few contributions to other life forms on earth.
  - A. True
  - B. False
  
2. Plants and algae use energy from the sun to produce organic molecules.
  - A. True
  - B. False
  
3. While carrying out photosynthesis, plants give off \_\_\_\_\_.
  - A. carbon dioxide
  - B. oxygen
  - C. water
  - D. All of the above.
  
4. \_\_\_\_\_ is required for photosynthesis to proceed.
  - A. carbon dioxide
  - B. light energy
  - C. water
  - D. All of the above.
  
5. In photosynthesis, \_\_\_\_\_ converted into chemical bond energy.
  - A. sugar is
  - B. chemicals are
  - C. light energy is
  - D. oxygen molecules are

6. Plants and algae provide \_\_\_\_\_.

- A. an important link in the food chain
- B. oxygen to the atmosphere
- C. Both A and B.
- D. Neither A nor B

**Quiz #2**  
**CHARACTERISTICS OF LIGHT**

1. Light has both wave-like and particle-like characteristics.
  - A. True
  - B. False
  
2. The distance from one peak to the next peak in light waves is \_\_\_\_\_.
  - A. always the same
  - B. known as the wavelength
  - C. of little importance in photosynthesis
  - D. All of the above.
  
3. Light discernible by the human eye \_\_\_\_\_.
  - A. makes up the visible light spectrum
  - B. is composed of clear light
  - C. represents every possible wavelength
  - D. is unusable by plants in photosynthesis
  
4. A photon is \_\_\_\_\_.
  - A. a slow moving light wave
  - B. identical to a proton
  - C. similar to a proton
  - D. a particle of light
  
5. White light is \_\_\_\_\_.
  - A. a blend of all wavelengths of light
  - B. separated into different colors by a prism
  - C. Both A and B.
  - D. Neither A nor B.

6. Of light discernible by the human eye, \_\_\_\_\_ has the shortest wavelength and \_\_\_\_\_ has the longest wavelength.
- A. green, yellow
  - B. yellow, green
  - C. red, violet
  - D. violet, red

**Quiz #3**  
**CHLOROPLASTS AND PIGMENTS**

1. Chloroplasts are the organelles in which photosynthesis takes place.
  - A. True
  - B. False
2. Outside of chloroplasts are disc-shaped structures known as thylakoids.
  - A. True
  - B. False
3. A stack of thylakoids is known as \_\_\_\_\_ and several stacks together make up \_\_\_\_\_.
  - A. an organ, an organelle
  - B. a pigment, an antenna assembly
  - C. a photosynthetic group, a photosynthetic cluster
  - D. None of the above.
4. Within the chloroplast is a thick fluid known as \_\_\_\_\_.
  - A. granna
  - B. grannum
  - C. stroma
  - D. stromum
5. Found within thylakoid membranes are \_\_\_\_\_ which can absorb light.
  - A. electrons
  - B. chloroplasts
  - C. pigments
  - D. water molecules
6. Green plants do not absorb \_\_\_\_\_ light.
  - A. yellow
  - B. green
  - C. red

7. \_\_\_\_\_ are common light-absorbing molecules.
- A. chlorophyll *a* and chlorophyll *b*
  - B. the carotenoids
  - C. Both A and B.
  - D. None of the above.
8. Chlorophyll *a* is \_\_\_\_\_.
- A. a pigment found only in bacteria
  - B. a bacteria found only in plants
  - C. unable to absorb light in the visible part of the spectrum
  - D. the main photosynthetic pigment

**Quiz #4**  
**THE ANTENNA COMPLEX**

1. An antenna complex is a group of photosynthetic pigments.
  - A. True
  - B. False
  
2. When \_\_\_\_\_, pigments release electrons.
  - A. excited
  - B. in the ground state
  - C. absorbed
  - D. exposed to oxygen
  
3. When pigments in an antenna complex release electrons, these electrons move to \_\_\_\_\_ and then to \_\_\_\_\_.
  - A. the acceptor molecule, the reactions center
  - B. the reaction center, the acceptor molecule
  - C. the thylakoid, the chloroplast
  - D. the chloroplast, the thylakoid
  
4. A photosystem consists of \_\_\_\_\_.
  - A. an antenna complex, the thylakoid, and the chloroplast
  - B. the thylakoid, the reaction center, and the acceptor molecule
  - C. the chloroplast, the acceptor molecule, and the antenna complex
  - D. an antenna complex, the reaction center, and the acceptor molecule
  
5. The two photosystems involved in photosynthesis are \_\_\_\_\_.
  - A. Photosystem I and Photosystem II
  - B. Photosystem A and Photosystem B
  - C. Photosystem a and Photosystem b
  - D. Photosystem Ia and Photosystem Ib



6. The first series of reactions in photosynthesis are collectively known as the \_\_\_\_\_.

- A. light reactions
- B. first reactions
- C. thylakoid reactions
- D. primary reactions

**Quiz #5**  
**THE LIGHT REACTIONS**

1. ATP and NADPH are special, energy-storing molecules.
  - A. True
  - B. False
  
2. The first series of reactions in photosynthesis takes its name from the fact that \_\_\_\_\_.
  - A. light is required
  - B. light is not required
  - C. the reagents have very little weight
  
3. The first step in the light reactions occurs when \_\_\_\_\_.
  - A. a pigment in Photosystem II absorbs a photon
  - B. a pigment in Photosystem I reflects a photon
  - C. a pigment in Photosystem I absorbs an electron
  - D. a pigment in Photosystem II reflects a photon
  
4. In the \_\_\_\_\_ state, pigments release \_\_\_\_\_.
  - A. ground, O<sub>2</sub>
  - B. excited, photons
  - C. ground, electrons
  - D. excited, electrons
  
5. Once electrons reach the \_\_\_\_\_, they are passed to an electron transport chain.
  - A. excited state
  - B. acceptor molecule
  - C. ground state
  - D. reaction center

6. Electrons leaving \_\_\_\_\_ are replaced by electrons provided when \_\_\_\_\_.
- A. Photosystem II, water molecules are split
  - B. Photosystem II, carbon dioxide is split
  - C. Photosystem II, oxygen is split
  - D. Photosystem I, oxygen is split
7. For each \_\_\_\_\_ lost by the photosystem in question # 6, \_\_\_\_\_ is split.
- A. electron, a pair of water molecules
  - B. pair of electrons, a water molecule
  - C. electron, one O<sub>2</sub> (oxygen) molecule
  - D. pair of electrons, one O<sub>2</sub> (oxygen) molecule
8. When \_\_\_\_\_ is split, \_\_\_\_\_ is released into the atmosphere.
- A. oxygen, water
  - B. oxygen, hydrogen
  - C. water, oxygen
  - D. water, hydrogen
9. As electrons slide along the electron transport chain connecting the two photosystems, \_\_\_\_\_.
- A. water is produced
  - B. ATP is produced
  - C. NADPH is produced
  - D. All of the above.

**Quiz #6**  
**THE LIGHT REACTIONS / ELECTRON FLOW**

1. Electrons enter Photosystem I in a higher state of energy than when they left Photosystem II.
  - A. True
  - B. False
  
2. Pigments in Photosystem I are unable to absorb light.
  - A. True
  - B. False
  
3. Electrons leaving Photosystem I are replaced by \_\_\_\_\_.
  - A. incoming photons
  - B. incoming protons
  - C. electrons supplied by the breakdown of glucose
  - D. the stream of electrons arriving from Photosystem II
  
4. Electrons leaving Photosystem I can follow \_\_\_\_\_.
  - A. one path only (the ETC leading back to Photosystem II)
  - B. one of two paths
  - C. one of three paths
  - D. one path only (electron flow)
  
5. In cyclic electron flow, electrons leaving Photosystem I \_\_\_\_\_.
  - A. wind up back at Photosystem II
  - B. wind up back at Photosystem I
  - C. wind up at the enzyme NADP<sup>+</sup> reductase
  - D. wind up at the enzyme ATP synthase

6. Electrons in cyclic electron flow are involved in the production of \_\_\_\_\_.
- A. oxygen
  - B. water
  - C. ATP
  - D. NADPH
7. In non-cyclic electron flow, electrons leaving photosystem I \_\_\_\_\_.
- A. wind up back at Photosystem II
  - B. wind up back at Photosystem I
  - C. wind up at the enzyme NADP<sup>+</sup> reductase
  - D. wind up at the enzyme ATP synthase
8. Electrons in non-cyclic electron flow are involved in the production of \_\_\_\_\_.
- A. oxygen
  - B. water
  - C. ATP
  - D. NADPH
9. With both photosystems working in conjunction with one another, there is a continuous stream of electrons moving from \_\_\_\_\_ to \_\_\_\_\_.
- A. oxygen, ATP
  - B. water, NADPH
  - C. Photosystem I, Photosystem II
  - D. glucose, Photosystem II

**Quiz #7**  
**ATP GENERATION**

1. H<sup>+</sup>, hydrogen ion, and proton all refer to the different things.
  - A. True
  - B. False
2. Electrons slide along the ETC and onto ATP molecules.
  - A. True
  - B. False
3. Electrons sliding along the ETC provide the energy to \_\_\_\_\_.
  - A. excite pigments along the ETC
  - B. split water molecules
  - C. pump protons from the stroma into the thylakoid compartment
  - D. pump protons from the thylakoid compartment into the stroma
4. An important part of ATP generation in photosynthesis is \_\_\_\_\_.
  - A. the proton development
  - B. the proton gradient
  - C. the proton receptor
  - D. the proton response
5. Protons want to move \_\_\_\_\_.
  - A. from low concentration to high concentration
  - B. from the stroma into the thylakoid compartment
  - C. from the thylakoid compartment into the stroma
  - D. from photosystem I to photosystem II
6. The enzyme ATP synthase \_\_\_\_\_.
  - A. generates ATP on the stroma side of the thylakoid membrane
  - B. allows protons to pass through the thylakoid membrane
  - C. adds an inorganic phosphate group to ADP molecules
  - D. All of the above.

**Quiz #8**  
**THE DARK REACTIONS**

1. The dark reactions take their name from the fact that no light is required for them to proceed.
  - A. True
  - B. False
  
2. The dark reactions lead to the production of organic molecules.
  - A. True
  - B. False
  
3. ATP and NADPH produced during the light reactions are not involved in the dark reactions.
  - A. True
  - B. False
  
4. The dark reactions are often referred to as the \_\_\_\_\_ Cycle.
  - A. Krebs
  - B. Calvin
  - C. Coolidge
  - D. Glucose
  
5. Plants use \_\_\_\_\_ in the production of glucose.
  - A. ATP
  - B. NADPH
  - C. CO<sub>2</sub>
  - D. All of the above.
  
6. Glucose contains \_\_\_\_\_ carbon atoms
  - A. a pair of
  - B. four
  - C. six
  - D. eight

7. In the first stage of the dark reactions, \_\_\_\_\_ is combined with \_\_\_\_\_.
- A. CO<sub>2</sub>, RuBP
  - B. NADPH, glucose
  - C. PGAL, RuBP
  - D. PGAL, CO<sub>2</sub>
8. The molecules produced in question #6 \_\_\_\_\_.
- A. split to form PGAL
  - B. link together to form PGAL
  - C. split to form RuBP
  - D. link together to form RuBP
9. \_\_\_\_\_ molecules of \_\_\_\_\_ are joined to form glucose.
- A. Two, RuBP
  - B. Four, RuBP
  - C. Two, PGAL
  - D. Four, PGAL
10. At the end of the dark reactions, \_\_\_\_\_ is converted back into \_\_\_\_\_.
- A. PGAL, RuBP
  - B. RuBP, PGAL
  - C. glucose, PGAL
  - D. glucose, RuBP



## Photosynthesis COMPREHENSIVE EXAM

**Please determine if the following statements are True or False.**

1. Photosynthetic organisms such as plants and algae make very few contributions to other forms of life on earth.  
A. True  
B. False
2. Plants and algae use energy from the sun to make organic molecules.  
A. True  
B. False
3. Light has both wave-like and particle-like qualities.  
A. True  
B. False
4. The distance between two adjacent peaks on a light wave is known as the frequency.  
A. True  
B. False
5. Chloroplasts are organelles in which photosynthesis takes place.  
A. True  
B. False
6. Lying outside of chloroplasts are structures known as thylakoids.  
A. True  
B. False

7. Pigments are molecules able to emit light waves.
  - A. True
  - B. False
  
8. An antenna complex is a group of photosynthetic pigments.
  - A. True
  - B. False
  
9. ATP and NADPH are special, energy-storing molecules.
  - A. True
  - B. False
  
10. H<sup>+</sup>, hydrogen ion, and proton all refer to different things.
  - A. True
  - B. False
  
11. Electrons slide along the electron transport chain and onto ATP molecules.
  - A. True
  - B. False
  
12. The dark reactions take their name from the fact that no light is required for them to proceed.
  - A. True
  - B. False
  
13. The dark reactions lead to the production of organic molecules.
  - A. True
  - B. False

**In the following portion of the exam, please choose the letter beside the word, words, or phrase that best completes each sentence.**

14. While carrying out photosynthesis, plants give off \_\_\_\_\_.

- A. carbon dioxide
- B. oxygen
- C. water
- D. All of the above.

15. In photosynthesis, \_\_\_\_\_ converted into chemical bond energy.

- A. sugar is
- B. chemicals are
- C. light energy is
- D. oxygen molecules are

16. Light discernible by the human eye \_\_\_\_\_.

- A. makes up the visible light spectrum
- B. cannot be used by plants
- C. represents every possible wavelength
- D. A and B only

17. A photon is \_\_\_\_\_.

- A. a slow moving light wave
- B. identical to a proton
- C. similar to a proton
- D. a particle of light

18. White light is \_\_\_\_\_.

- A. a blend of all wavelengths of light
- B. separated into different colors by a prism
- C. Both A and B.
- D. All of the above.

19. A stack of thylakoids is known as \_\_\_\_\_ and several stacks together make up \_\_\_\_\_.

- A. an organ, an organelle
- B. a pigment, an antenna assembly
- C. a photosynthetic group, a photosynthetic cluster
- D. None of the above.

20. Within the chloroplast is a thick fluid known as \_\_\_\_\_.

- A. granna
- B. grannum
- C. stroma
- D. stromum

21. Absorption of light takes place \_\_\_\_\_.

- A. inside of the thylakoid
- B. on the cell wall of plant cells
- C. on the thylakoid membrane
- D. None of the above.

22. Chlorophyll a is \_\_\_\_\_.

- A. a pigment found only in bacteria
- B. a bacteria found only in plants
- C. unable to absorb light in the visible spectrum
- D. the main photosynthetic pigment

23. When \_\_\_\_\_, pigments release electrons.

- A. excited
- B. in the ground state
- C. absorbed
- D. exposed to oxygen

24. A photosystem consists of \_\_\_\_\_.
- A. an antenna complex, the thylakoid, and the chloroplast
  - B. the thylakoid, the reaction center, and the acceptor molecule
  - C. the chloroplast, the acceptor molecule, and the antenna complex
  - D. an antenna complex, the reaction center, and the acceptor molecule
25. Electrons leaving Photosystem II enter an \_\_\_\_\_.
- A. electron transfer chain
  - B. electron transport chain
  - C. electric transfer chain
  - D. electric transport chain
26. Electrons leaving \_\_\_\_\_ are replaced by electrons provided when \_\_\_\_\_.
- A. Photosystem I, oxygen is split
  - B. Photosystem II, oxygen is split
  - C. Photosystem II, glucose is broken down
  - D. Photosystem II, water is split
27. When \_\_\_\_\_ is split, \_\_\_\_\_ is released into the atmosphere.
- A. oxygen, water
  - B. oxygen, hydrogen
  - C. water, oxygen
  - D. water, hydrogen
28. Electrons leaving Photosystem I are replaced by \_\_\_\_\_.
- A. incoming photons
  - B. incoming protons
  - C. electrons supplied by the breakdown of glucose
  - D. the stream of electrons arriving from Photosystem II

29. Electrons leaving Photosystem I can follow \_\_\_\_\_.
- A. one path only (the ETC leading back to Photosystem I)
  - B. one of two paths
  - C. one of three paths
  - D. one path only
30. In cyclic electron flow, electrons \_\_\_\_\_.
- A. wind up back at Photosystem II
  - B. wind up back at Photosystem I
  - C. wind up at the enzyme NADP<sup>+</sup> reductase
  - D. wind up at the enzyme ATP reductase
31. Electrons in cyclic electron flow are involved in the production of \_\_\_\_\_.
- A. oxygen
  - B. water
  - C. ATP
  - D. NADPH
32. In non-cyclic electron flow, electrons \_\_\_\_\_.
- A. wind up back at Photosystem II
  - B. wind up back at Photosystem I
  - C. wind up at the enzyme NADP<sup>+</sup> reductase
  - D. wind up at the enzyme ATP reductase
33. With both photosystems working in conjunction with one another, there is a continuous flow of electrons from \_\_\_\_\_ to \_\_\_\_\_.
- A. oxygen, ATP
  - B. water, NADPH
  - C. Photosystem I, Photosystem II
  - D. glucose, Photosystem I

34. Electrons sliding along the ETC between the photosystems provide the energy to \_\_\_\_\_.
- A. excite pigments along the ETC
  - B. split water molecules
  - C. pump protons from the stroma into the thylakoid compartment
  - D. pump protons from the thylakoid compartment into the stroma
35. An important part of ATP generation in photosynthesis is \_\_\_\_\_.
- A. the proton development
  - B. the proton receptor
  - C. the proton response
  - D. the proton gradient
36. Protons want to move \_\_\_\_\_.
- A. from low concentration to high concentration
  - B. from the stroma into the thylakoid compartment
  - C. from the thylakoid compartment into the stroma
  - D. from Photosystem I to Photosystem II
37. Plants use \_\_\_\_\_ in the production of glucose.
- A. ATP
  - B. NADPH
  - C. CO<sub>2</sub>
  - D. All of the above
38. Glucose contains \_\_\_\_\_ carbon atoms.
- A. a pair of
  - B. four
  - C. six
  - D. eight

39. In the first stage of the Calvin Cycle, \_\_\_\_\_ is combined with \_\_\_\_\_.

- A. CO<sub>2</sub>, RuBP
- B. NADPH, glucose
- C. PGAL, RuBP
- D. PGAL, CO<sub>2</sub>

40. The molecules produced in question #39 \_\_\_\_\_.

- A. split to form PGAL
- B. link together to form PGAL
- C. split to form RuBP
- D. link together to form RuBP

41. At the end of the Calvin Cycle, \_\_\_\_\_ is converted back into \_\_\_\_\_.

- A. PGAL, RuBP
- B. RuBP, PGAL
- C. glucose, PGAL
- D. glucose, RuBP

**In the following portion of the exam, please fill in the word or words that best completes each sentence.**

42. Plants that appear green in color do not absorb \_\_\_\_\_ light.

43. The first series of reactions in photosynthesis (in which light is absorbed) are collectively known as the \_\_\_\_\_.

44. Electrons leaving the reaction centers of either photosystem I or photosystem II are first passed to \_\_\_\_\_.

45. As electrons slide along the ETC connecting the two photosystems, \_\_\_\_\_ is produced.

46. Electrons in non-cyclic electron flow are involved in the production of \_\_\_\_\_.



47. An enzyme critical to ATP production in photosynthesis is

\_\_\_\_\_.

48. In the Calvin Cycle, two molecules of \_\_\_\_\_ are used to form one molecule of glucose.

## Photosynthesis ANSWER GUIDE

### QUIZ PACK

QUIZ #1	QUIZ #2	QUIZ #3	QUIZ #4	QUIZ #5	QUIZ #6	QUIZ #7	QUIZ #8
1. B	1. A	1. A	1. A	1. A	1. B	1. B	1. A
2. A	2. B	2. B	2. A	2. A	2. B	2. B	2. A
3. B	3. A	3. D	3. B	3. B	3. D	3. C	3. B
4. D	4. D	4. C	4. D	4. D	4. B	4. B	4. B
5. C	5. C	5. C	5. A	5. B	5. B	5. C	5. D
6. C	6. D	6. B	6. A	6. A	6. C	6. D	6. C
		7. C		7. B	7. C		7. A
		8. D		8. C	8. D		8. A
				9. B	9. B		9. C
							10. A

### COMPREHENSIVE EXAM

1. B	11. B	21. C	31. C	41. A
2. A	12. A	22. D	32. C	42. green
3. A	13. A	23. A	33. B	43. light reactions
4. B	14. B	24. D	34. C	44. an acceptor molecule
5. A	15. C	25. B	35. D	45. atp
6. B	16. A	26. D	36. C	46. nadph
7. B	17. D	27. C	37. D	47. atp synthase
8. A	18. C	28. D	38. C	
9. A	19. D	29. B	39. A	
10. B	20. C	30. B	40. A	

## Photosynthesis GLOSSARY

**acceptor molecule:** a molecule that accepts excited electrons from the reaction center of a photosystem. The acceptor molecule then sends excited electrons down an electron transport chain.

**adenosine triphosphate (ATP):** high energy molecule that helps fuel the dark reactions in photosynthesis.

**bacteria:** one-celled, prokaryotic organisms.

**Calvin Cycle:** in the dark reactions stage of photosynthesis, a series of reactions in which carbon dioxide is converted into glucose. The Calvin Cycle is made possible by the use of ATP and NADPH molecules produced during the light reactions.

**Carbon Dioxide (CO<sub>2</sub>):** compound used during the dark reactions of photosynthesis. Provides carbon atoms incorporated into glucose molecules.

**carotenoids:** pigments that transfer light energy they absorb to chlorophyll a during photosynthesis.

**chlorophyll a:** a pigment molecule found in chloroplasts that absorbs light energy during photosynthesis. The main photosynthetic pigment.

**chlorophyll b:** a pigment that transfers light energy it absorbs to chlorophyll a during photosynthesis.

**chloroplasts:** specialized structures within plant cells that contain all the necessary components for the reactions in photosynthesis to occur.

**cyclic electron flow:** movement of electrons from the acceptor molecule in Photosystem I along a series of receptor molecules leading back to Photosystem I. Electrons in cyclic electron flow are involved in the generation of ATP.

**dark reactions:** the second stage of photosynthesis in which high energy molecules (ATP and NADPH) help to fuel reactions that convert carbon dioxide into glucose.

**electron:** a negatively charged particle with a very small mass.

**electron transport chain (ETC):** chain of receptor molecules associated with Photosystems I and II. Electron movement provides energy used in the production of ATP molecules.

**glucose** ( $C_6H_{12}O_6$ ): sugar molecule produced during the dark reactions of photosynthesis. Long term energy storage molecule.

**grana:** two or more stacks of thylakoids.

**granum:** a stack of thylakoids.

**light energy:** energy provided by light.

**light reactions:** the first stage of photosynthesis in which light energy is absorbed and converted to chemical bond energy in ATP and NADPH molecules.

**NADPH (Nicotinamide Adenine Dinucleotide Phosphate):** short-term energy storing molecule.

**non-cyclic electron flow:** movement of electrons from the acceptor molecule in Photosystem I along a series of receptor molecules leading to the enzyme NADP+ reductase. Electrons in non-cyclic electron flow are involved in the generation of NADPH.

**organelles:** structures having specific functions found within cells.

**oxygen** ( $O_2$ ): gas molecule; a waste product of photosynthesis.

**PGAL (Phosphoglyceraldehyde):** compound containing three carbon atoms produced in the dark reactions.

**photons:** particles of light.

**photosynthesis:** process by which plants absorb light energy from the sun and use it to convert water and carbon dioxide into glucose and oxygen.

**photosystem:** a group of pigment molecules, a reaction center, and acceptor molecule that function together during photosynthesis.

**pigment:** a substance that can absorb specific wavelengths of light.

**reaction center:** a special type of chlorophyll a molecule that accepts electrons from other chlorophyll a molecules in a photosystem.

**RuBP (Ribulose biphosphate):** compound involved in the dark reactions of photosynthesis. Binds with CO<sub>2</sub> entering the Calvin Cycle.

**stroma:** area within a chloroplast surrounding the grana. The dark reactions of photosynthesis occur in the stroma.

**thylakoids:** disk-like structures containing chlorophyll molecules; found in chloroplasts. Site of the light reactions.

**visible light spectrum:** portion of the spectrum composed of wavelengths detectable by the human eye.

**water (H<sub>2</sub>O):** compound broken down during the light reactions of photosynthesis. Provides electrons and protons (hydrogen ions) for later use.