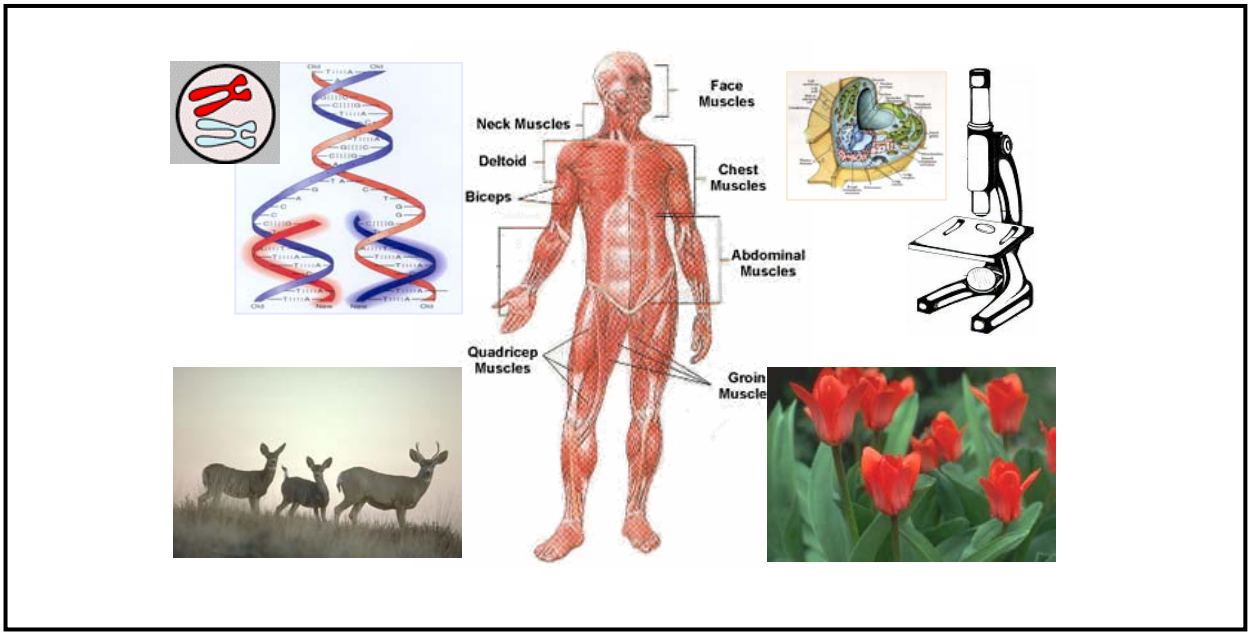
Project EASE

(Effective Alternative Secondary Education)

BIOLOGY



MODULE 4

Photosynthesis

BUREAU OF SECONDARY EDUCATION
Department of Education
DepED Complex, Meralco Avenue
Pasig City

Module 4
Photosynthesis

What this module is about

Many people would like to live in places full of plants. Why? The place is always cool; it is less dusty and it has abundant water supply. Plants are great food providers. How do plants make food? The food-making process of plants is the main concern of this module. The module includes the following lessons:

- **Lesson 1 – The Sunlight**
- **Lesson 2 – The Leaf**
- **Lesson 3 – Chloroplast and Photosynthetic Pigments**
- **Lesson 4 – Light-dependent Reaction**
- **Lesson 5 – Light-independent Reaction**

What you are expected to learn

After going through this module, you are expected to:

1. Name the factors important to the food-making process.
2. Describe the chloroplast.
3. Name the pigments and describe how pigments are organized in order to trap sunlight efficiently.
4. Differentiate light-dependent reaction from light-independent reaction of photosynthesis.
5. Correlate the internal structure of the leaves to the food-making process of plants.

How to learn from this module

Here's a simple guide for you in going about the module:

1. Read the instruction carefully.
2. Take the pretest before reading the rest of the module.

3. Do all activities and exercises.
4. Use the concepts discussed in each lesson to explain the results of the activities or exercises.
5. Take the posttest after you have finished the lessons and performed all activities or exercises.

What to do before (Pretest)

Multiple Choice. Choose the letter of the best answer. Write the chosen letter on a separate sheet of paper.

1. The color of the leaves is green. This means that the green light is
   a. absorbed
   b. deflected
   c. reflected
   d. transmitted

2. Which of the following substances is the origin of oxygen released as oxygen gas by green plants during photosynthesis?
   a. water
   b. sugar
   c. carbon dioxide
   d. ribulose-1,5-biphosphate

3. Which of the following gases is important to photosynthesis?
   a. ozone gas
   b. oxygen gas
   c. water vapor
   d. carbon dioxide

4. In which of the following cellular organelles does photosynthesis occur?
   a. ribosome
   b. chloroplast
   c. chlorophyll
   d. mitochondrion

5. Pigments are needed by plants to trap energy from the sun. Which of the following is the most important pigment for trapping energy?
   a. carotenoid
   b. xanthophylls
   c. chlorophyll b
   d. chlorophyll a

6. The final acceptor of the electron during noncyclic electron pathway is
   a. photosystem I
   b. photosystem II
   c. ATP
   d. $NADP^+$

7. What is the temperature in which ribulose biphosphate carboxylase utilizes oxygen gas?
   a. below 30 ^oC
   b. at 30 ^oC
   c. above 30 ^oC
   d. undetermined

8. What is the special cholorophyll pigment that serves as primary reaction center of photosystem I?
    a. P 700
    b. P 680
    c. carotene
    d. xanthophylls

9. Where do we find the water splitting mechanism of the light – dependent reaction of photosynthesis?
    a. photosystem I
    b. photosystem II
    c. primary reaction center
    d. has not been identified

10. Which of the following substances screened out the high-energy components of solar energy and prevented it from reaching the surface of the earth?
    a. carbon dioxide
    b. cloud
    c. ozone
    d. water

11. Which of the following rays of light has the lowest energy content?
    a. blue
    b. green
    c. red
    d. yellow

12. Which of the following components of the solar energy has the shortest wavelength?
    a. ultraviolet rays
    b. visible light
    c. violet light
    d. gamma rays

13. How do you call the sack-like structure in the chloroplast?
    a. stroma
    b. thylakoid
    c. matrix
    d. granum

14. Where does the light-independent reaction occur?
    a. stroma
    b. grannum
    c. lamella
    d. thylakoid

15. How do you call the organization of photosynthetic pigments?
    a. photosystem
    b. water-splitting complex
    c. electron transport chain
    d. light harvesting antennae

16. Which of the following is the first stable product of photosynthesis?
    a. pyruvic acid
    b. phosphoglyceric acid
    c. phosphoglyceraldehyde
    d. ribulose-1,5-biphosphate

17. What is the enzyme that plays an important role in carbon dioxide fixation?
    a. phosphatase
    b. ribulose-1,5-oxygenase
    c. ribulose-1,5-biphosphate
    d. phosphoenol pyruvate carboxylase

18. Landscaping is a very lucrative business today. Which of the following plants can be planted in sunlit ground of a house or building?
    a. bermuda
    b. peanut grass
    c. carabao grass
    d. all of them

19. Light-dependent reaction of photosynthesis must come first step before the light-independent reaction because its products are important to the fixation of carbon dioxide. Which of the following is/are the product/s of light –dependent reaction?
    a. ADP only
    b. ATP only
    c. NADPH only
    d. NADPH and ATP

20. Which plants grow well in the tropics like the Philippines?
    a. rice
    b. pine tree
    c. pineapple
    d. a and c

Key to answers on page 26.

Be familiar with the following terms:

Terms	Definition
Pigment	Colored substance present in plants
Light-dependent	Process which occurs in the presence of light
Light-independent	Process which does not require light
Carbon dioxide fixation	Process which converts carbon dioxide into carbohydrate
Cyclic photophosphorylation	Production of ATP in a cyclic manner
Non-cyclic photophosphorylation	Production of ATP in Z-pathway
Photorespiration	Process wherein oxygen gas competes with carbon dioxide in reacting with ribulose-1,5-biphosphate
z-pathway	Is the pathway followed by excited electrons from photosystem II. It is a non-cyclic flow of electron.
Photosystem	Organization of pigments
C3 plant	Plant that fixes CO_2 to yield 3-carbon phosphoglyceraldehyde as the first stable product of photosynthesis
C4 plant	Plant that fixes CO_2 -4-carbon malate when temperature is above 30 ^{o}C
CAM plant	Plant in arid environment wherein CO_2 is fixed at night and released to Calvin Cycle at day time
Variegated leaf	A leaf with patches or margins that are not colored green

Lesson 1. Sunlight

All processes that occur in living and non-living systems require energy. Photosynthesis is no exception. The energy that comes from the sun is called solar energy. It travels as wave and is described in terms of its energy content and its wavelength. It comes as discrete packets called photons. The component of solar energy that is important to photosynthesis is the visible light. Visible light is a white light. What makes up the visible light? Discover it as you perform the activity below.

What you will do

Activity 1.1 Components of the visible light

What you need: prism
white paper
light source

Procedure:

1. Arrange the three objects as shown below
   light source prism white paper
2. Switch the light source on and focus the light into the prism.
3. What do you see in the white paper that serves as screen? Describe it.
4. Draw what you see on the white paper

Key to answers on page 26.

When you focused the light into the prism, you saw a rainbow of colors in the white paper similar to Figure 1. The visible light broke up into violet, blue, blue-green, green, yellow-green, yellow, orange and red.

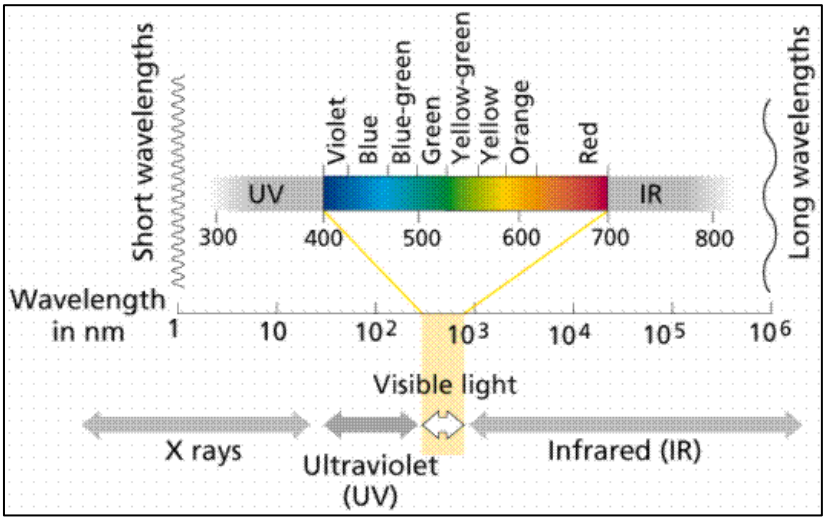


Figure 1
Components of solar energy

The components of solar energy before the visible light have short wavelengths such as gamma rays, x-rays and ultraviolet rays. You do not see them. Short-wavelength components have more energy. Those components after the visible light have long wavelength. These are also invisible to our naked eyes. They possess less energy.

Only 42 % of the solar energy passes through the atmosphere and reaches the earth. High energy, short wavelengths are screened out by ozone and the lower energy long wavelengths are screened out by water and carbon dioxide in air. Only 2 % of the light that reaches the earth is utilized in photosynthesis.

What you will do

Self-Test 1.1

Multiple Choice. Choose the letter of the best answer. Write the chosen letter on a separate sheet of paper.

1. Which of the following components of solar energy has long wavelength?
   a. gamma rays
   b. visible light
   c. microwaves
   d. radiowaves

2. Which of the following components of solar energy has the most energy?
   a. visible light
   b. infrared rays
   c. ultraviolet rays
   d. violet light

3. Which of the following screens out low energy wavelengths of the solar energy?
   a. water
   b. ozone
   c. carbon dioxide
   d. carbon dioxide and water

Key to answers on page 26.

Lesson 2. The Leaf

Plant leaves absorb sunlight to manufacture plant sugars through a process called **photosynthesis**. In order to get enough light, leaf surfaces are flattened to have a big area as shown in Figure 2. Let us do Activity 2.1 to get a closer view of the external structure of plant leaves.

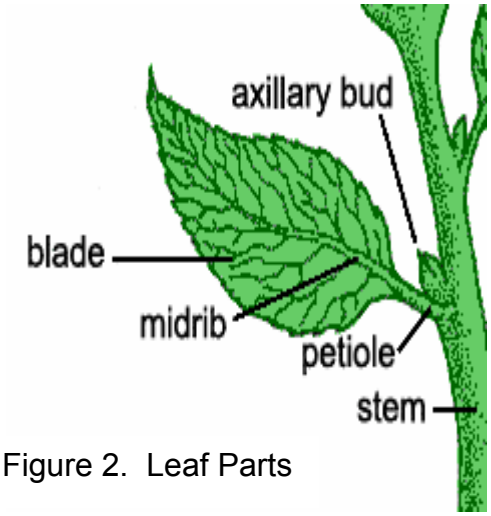


Figure 2. Leaf Parts

The blade is a thin expanded structure on either side of the midrib and is the largest part of the leaf. The leaf is attached to the stem by a petiole. The base of the petiole is attached to the node of the stem. The node where a petiole meets a stem is called a leaf **axil**. The axil contains single buds or bud clusters, referred to as axillary buds. You can also see a pair of appendages at the base of the petiole called **stipules**. Stipules protect the young leaf and may be modified into spines or tendrils.

What you will do

Activity 2.1 Leaf Characteristics

What you need: Notebook and pencil

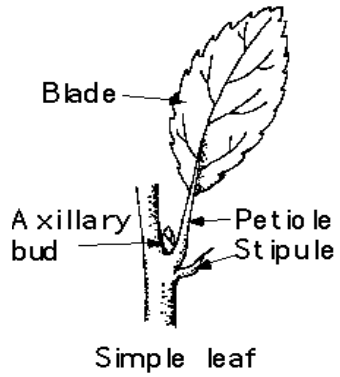
What to do:

1. You may have a garden, park or farm in your place. Visit the farm, garden or park.
2. Note the different characteristics of the leaf of the plants you may find in the place.

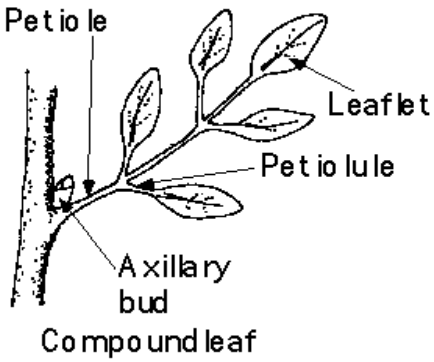
Key to answers on page 26

From your visit to the park, garden or farm, you must have seen several leaf characteristics. Most of these characteristics make leaves very efficient in trapping energy from the sun, which in turn, increases the photosynthetic activity of the leaves. Some of these characteristics are the following:

- **Leaf structure**



Simple leaves have a single blade.



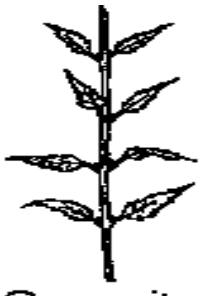
Compound leaves have more than one blade on a single petiole. The multiple blades of a compound leaf are called leaflets.

- **Leaf Attachment**

Petiolate
The blade is attached to the stem by a petiole

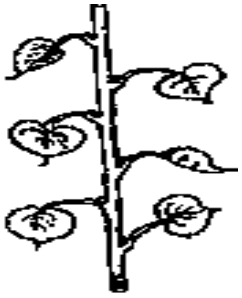
Sessile
The blade is attached directly to the stem without a petiole.

- **Leaf Arrangement**



Opposite

Two leaves grow opposite each other at each node.



Alternate

One leaf grows at each node. The leaves alternate sides along the stem.

Whorled

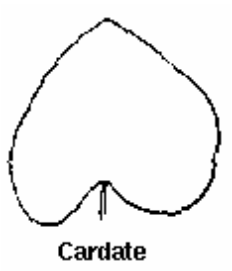
Several leaves grow around a single node.

- **Leaf Shape**

Narrow from base to tip

Oval-shaped

Wide at the base and narrow at the tip



Heart-shaped

Deeply lobed like the fingers of a hand

- **Leaf Margins**

Entire

The edge of the leaf is smooth.

Crenate

The edge has rounded indentations

Serrate

The edge of the leaf is finely toothed.

Lobed

The edge of the leaf is deeply indented.

Where does photosynthesis occur in the leaf of plants? You shall do Activity 2.2 to find out which parts of the leaves are involved in photosynthesis.

What you will do

Activity 2.2 Where does photosynthesis happen?

What you need:			
	petri dish	iodine solution	any variegated leaf
	ethyl alcohol	200 mL beaker	alcohol lamp
	tripod	wire gauze	water
	water bath	medicine dropper	

What you will do:

1. Get a variegated leaf.
2. Draw this leaf and indicate the patches or margins that are not colored green
3. Place the leaf in a beaker with water and boil the leaf to remove the water-soluble red and blue pigments.
4. Replace the water with ethyl alcohol, place the beaker in a water bath and apply heat. Be careful because the alcohol is volatile.
5. Pour out the alcohol, replace it with water and apply heat.
6. Spread out the leaf free of pigments carefully in a petri dish.
7. Cover the leaf with a few drops of iodine solution.
8. Observe.
9. A blue black or dark purple coloration in the leaf indicates the presence of starch.
10. Draw the leaf. Darken the parts of the leaf you observed to contain starch.
11. Compare the second drawing of the leaf with the first drawing you made.

Iodine solution is a test for starch. In the activity, the green part of the leaf turned blue black in the presence of iodine solution. This indicated that starch was present. The green part of the leaf carried out photosynthesis. This observation was not observed in the non-green part. Photosynthesis did not happen in the non-green part because there was no starch, an indicator of photosynthesis. Clearly, photosynthesis occurs only in the green parts of the plants such as the green leaves and the green stems of cactus.

Have you ever asked yourself what is inside the leaf that makes it a site for food production? Figure 3 shows the inside of the leaf.

In Figure 3, you can see layers of cells sandwiched by the lower and upper epidermis. This is called mesophyll layer, which is composed of palisade cells (arranged like columns) and spongy cells (loosely arranged cells). These cells have organelles that contain green pigments. These organelles are called ***chloroplasts***. Chloroplasts contain pigments that trap energy from the sun.

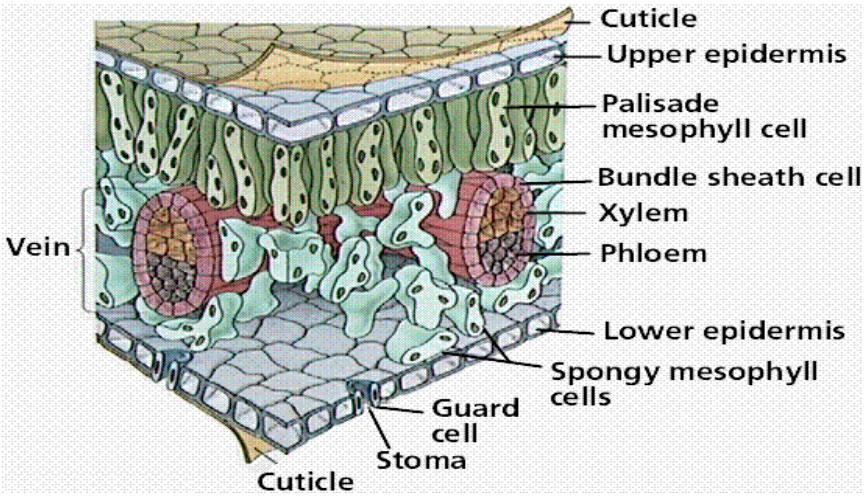


Figure 3. The inside of the leaf

At the lower epidermis, you will see some openings. Each opening is called **stoma** (stomata). This is where carbon dioxide enters and oxygen passes out. We shall look at the structure of the stoma. Perform Activity 2.3.

What you will do

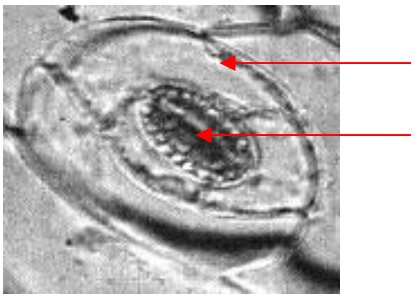
Activity 2.3 Observing the Stomata

What you need:

	leaf	glass slide
	forceps	water
	microscope	

What you will do:

1. Fold a leaf in half until it cracks.
2. Tear the leaf so that a part of the lower layer of cells appears as narrow, colorless border along the torn edge.
3. Remove a portion of the lower layer of cells with a pair of forceps.
4. Put the portion of the lower layer of cells in a glass slide. Add a drop of water.
5. Examine the slide under the low power objective.
6. Do you see some openings?



This is what you are supposed to see - the **stoma**, a slit-like structure. Around the stoma is a pair of bean-shaped cells called **guard cells**. The guard cell is an epidermal cell with chloroplast. It is the only epidermal cell that can carry out photosynthesis. It regulates the opening and the closing of the stoma.

Figure 4. The guard cell

What you will do

Self-Test 2.1

Multiple Choice. Choose the letter of the best answer. Write the chosen letter on a separate sheet of paper.

1. The main photosynthetic organ in the plant is the:
   a. stem
   b. root
   c. leaves
   d. flower

2. Which of the following organelles traps energy from the sun?
   a. epidermis
   b. cuticle
   c. chloroplast
   d. chlorophyll

3. Where do we find cells with chloroplasts in the leaves of plants?
   a. mesophyll layer
   b. cuticle
   c. epidermis
   d. matrix

4. Cactus makes food through its
   a. leaves
   b. stems
   c. roots
   d. flowers

5. Where do we find most of the stomata?
   a. upper epidermis
   b. mesophyll layer
   c. lower epidermis
   d. spongy layer

Key to answers on page 26.

Lesson 3. The Chloroplast and Other Photosynthetic Pigments

Many people find fulfillment by just looking at plants. Why? You see a myriad of colors in plants – violet, lavender, red, white, pink. These colored parts of plants are due to **pigments**. Pigments are chemical compounds, which reflect only certain wavelengths of visible light. This makes them appear "colorful". Flowers, corals, and even animal skin contain pigments, which give them their colors. Most leaves are green. Do you think leaves contain green pigments only? To answer this question, do activity 3.1

What you will do

Activity 3.1 How many kinds of pigments are there in green leaves?

What you need:
- alcohol
- mortar and pestle
- 2 pieces of green leaves
- beaker
- 1 piece of chalk

What you will do:

1. Get 2 pieces of leaves and clean them thoroughly.
2. Place the leaves in a mortar and pound with pestle along with grains of sand.
3. Add enough alcohol to cover the mixture.
4. Continue pounding until enough pigments are extracted.
5. Decant the extract into the beaker.
6. Dip a new piece of chalk into the extract and allow the extract to sip into the chalk.
7. Observe the piece of chalk. How many bands of colors do you see in it?

As you can see in the piece of chalk, it is not only the green pigment that is present in a green leaf. There are other pigments.

Pigments also absorb light rays of certain wavelength. In plants, algae, and cyanobacteria, pigments capture the energy of sunlight and use it in photosynthesis. Each pigment absorbs only certain rays of light. Plants possess several kinds of pigments. What are the different pigments that are important for photosynthesis? There are three basic groups of plant pigments.

- **Chlorophylls** are green pigments, which contain a ring that allows electrons to move freely so the molecule can gain or lose electrons easily. There are several kinds of chlorophylls – *chlorophyll a* is present in plants, algae and cyanobacteria; *chlorophyll b* is present in green algae and plants; and *chlorophyll c* is found only in photosynthetic diatoms, kelps and dinoflagellates.

- **Carotenoids** are usually red, orange, or yellow pigments. These compounds are composed of two small six-carbon rings connected by a "chain" of carbon atoms. They do not dissolve in water. Carotenoids absorb energy and pass it to chlorophyll. Carotenoid is an accessory pigment. An example of carotenoid is **fucoxanthin**, a brown pigment which colors brown algae like kelps and diatoms brown. Carotenoids also include carotene, which gives carrots their color.

- **Phycobilins** are water-soluble pigments, and are found in the cytoplasm, or in the stroma of the chloroplast. They occur only in Cyanobacteria and Rhodophyta. **Phycocyanin (**present in cyanobacteria**)** and **phycoerythrin (**found in red algae**)** are examples of phycobilins.

Within the thylakoid, pigments form clusters of 2-3 pigment molecules arranged around a pair of chlorophyll-a molecules. Some proteins are also found in this cluster. We call this cluster a ***photosystem.*** The outer pigments of the photosystem act like an antenna shuttling photons into chlorophyll-a in the reaction center.

There are two photosystems – photosystem I and photosystem II. Photosystem I absorbs red light at about 700 nanometer (nm) and its primary reaction center is the special chlorophyll called P 700. Photosystem II absorbs more orange light at 680 nm and its primary reaction center is the special chlorophyll called P 680. A water-splitting complex is associated with Photosystem II.

Where can we find the photosynthetic pigments? They are housed inside the chloroplast. Do Activity 3.2 to see the chloroplast of a leaf.

What you will do

Activity 3.2 Observing chloroplast

What you need: microscope glass slide
Hydrilla water

What will you do:

1. Get a hydrilla plant and place it in a wide-mouthed bottle.
2. Expose to sunlight for 15 minutes.
3. Detach healthy green leaf near the apex and mount it on water in a glass slide.
4. Examine the leaf under the low power objective and high power objective of the microscope
5. Do you see compartments? What is the shape of each compartment?
6. Observe the coin shape chloroplasts moving along with the cytoplasm.

Under the microscope you see compartments. In these compartments, you will notice some green bodies. These green bodies are the chloroplasts.

We shall describe the structure of the chloroplast. A chloroplast is enclosed by a double membrane – an outer membrane and an inner membrane. The outer membrane is smooth while the inner membrane is thrown into tube like structures. Between these membranes is a space called *intermembrane compartment*. Next to the inner membrane is a space called *stroma*. Stroma contains a complex mixture of enzymes and water. Embedded in the stroma is a complex network of stacked sacs.

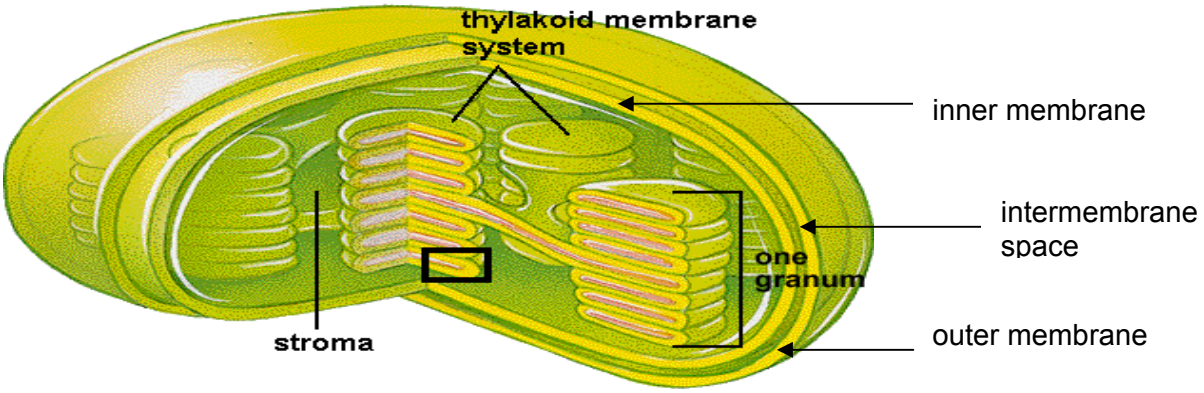


Figure 5. The chloroplast

Each stack is called a *granum* (grana). A granum is made up of flattened sacs called *thylakoid*. The photosynthetic pigments are found in thylakoids. Figure 5 is a typical structure of a chloroplast.

One granum is connected to another through stromal lamella. A chloroplast contains 40-60 grana. A granum may have two or three – hundred thylakoids.

What you will do

Self-Test 3.1

Multiple Choice. Choose the letter of the best answer. Write the chosen letter on a separate sheet of paper.

1. Where do we find the chlorophyll in the chloroplast?
   a. stroma
   b. thylakoid
   c. intermembrane compartment
   d. carotenes

2. What can we find in the stroma of the chloroplast?
   a. enzymes
   b. carotenes
   c. chlorophyll
   d. thykoid

3. Which of the following pigments is an accessory pigment?
   a. chlorophyll a
   b. P 700
   c. P 680
   d. carotenoid

4. The water-splitting complex is associated with which photosystem?
   a. photosystem I
   b. photosystem II
   c. both a and b

5. How do you call the space between the outer and the inner membrane?
   a. stroma
   b. thylakoid compartment
   c. intermembrane compartment
   d. stromal lamella

6. What makes up a granum?
   a. stromal lamella
   b. stroma
   c. thykoid
   d. none of these

Key to answers on page 26.

Lesson 4. The Light-dependent Reaction

Light-dependent reaction is the first phase of photosynthesis. In the previous lesson, we learned that pigment molecules form clusters called photosystems. The outer pigments serve as antennae for collecting solar energy. The energy is passed from pigment to pigment until it is concentrated at the special chlorophyll *a (P 700 in PS I and P 680 in PS II),* a part of the primary reaction center. The electrons become so excited that they escape as shown in Figure 6.

In PS 1, the excited electrons follow a cyclic path. You can see this in Figure 7. The electrons that escaped from the chlorophyll enter the electron transport system, a series of electron carriers. At the electron transport system, electrons are passed from one carrier to the next. In the process, energy is released and is used to pump hydrogen ions from stroma to thylakoid compartment. The amount of hydrogen ions in the thylakoid has potential energy.

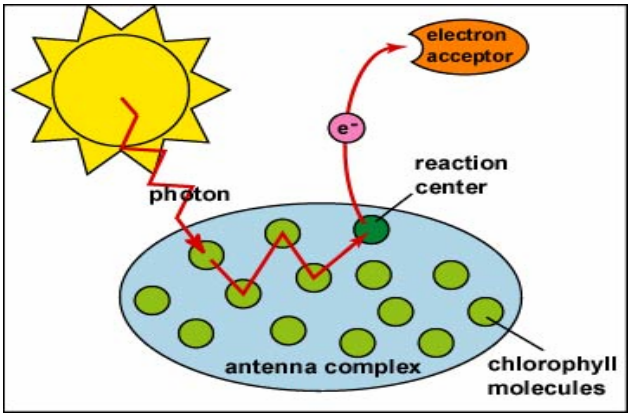


Figure 6. Photosystem

The electrons left the electron transport system with very low energy. The low- energy electrons return to PS I and repeat the cycle when the system absorbs solar energy.

What will happen to the hydrogen ions that possess potential energy? They flow from high concentration to low concentration, through a special protein called ***ATP synthetase complex*.**

As hydrogen ions flow from inside of thylakoid to the stroma, ATP is synthesized. The direction of the flow is shown in Figure 8.

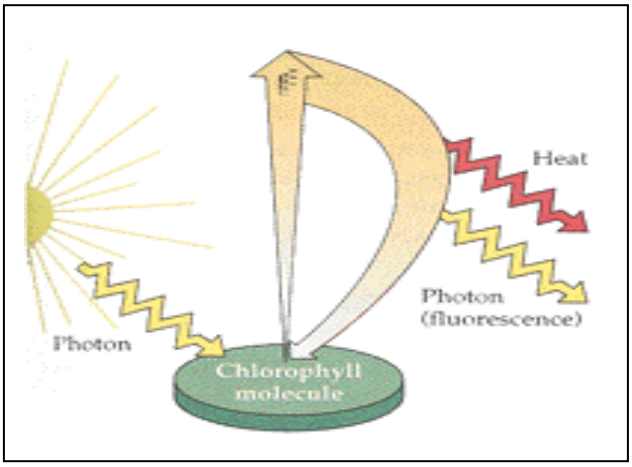


Figure 7
Cyclic electron flow involving PS I

$$ADP + P \rightarrow ATP + H_20$$

Since ATP is synthesized in the presence of light, the cyclic electron flow is also called ***cyclic photophosphorylation.***

Excited electrons may also follow a non-cyclic electron flow as shown in Figure 9. When does an excited electron follow a non-cyclic path? If PS II antenna complex absorbs solar energy, the high-energy electrons leave the reaction center- where **chlorophyll a** molecules are found and enter the electron transport system. Here, energy is released as electrons are passed from one carrier to another. The released energy is stored in the form of Hydrogen ion gradient. This gradient is

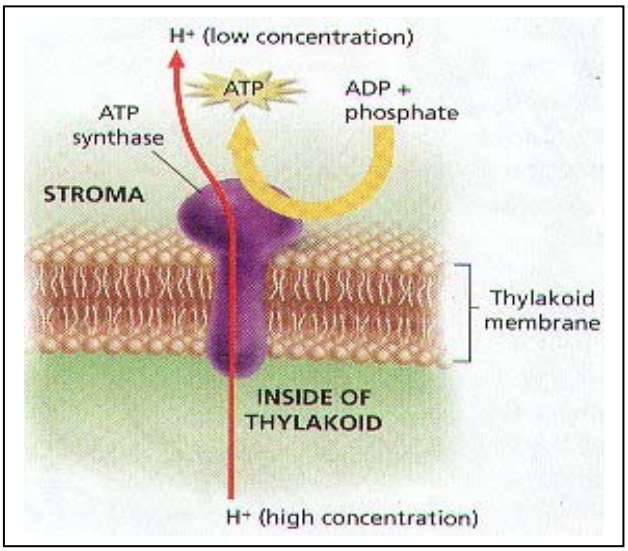


Figure 8
Hydrogen ions leave the thylakoid

used by enzyme, ATP synthase complex, to drive the synthesis of ATP.

$$ADP + P \dashrightarrow ATP + H_20$$

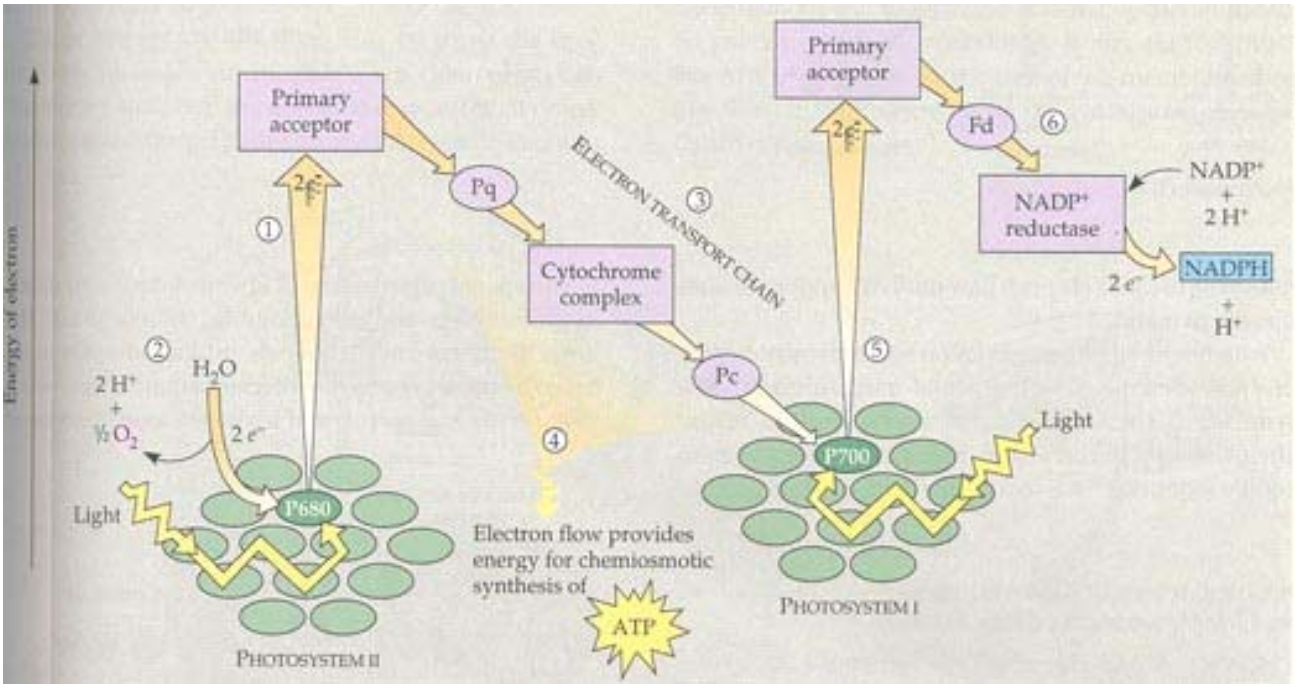
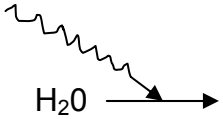


Figure 9. The non-cyclic flow of electrons

As you can see in Figure 9, the low-energy electrons move from the electron transport system to PS I where they gain energy when the pigments absorb solar energy. The excited electrons are passed to an electron carrier. The electron carriers send the energized electrons to oxidized nicotinamide dinucleotide phosphate ($NADP^+$), also an electron carrier. Together with the electron, $NADP^+$ picks up hydrogen ion from water to become NADPH.

This non-cyclic electron flow is also called Z-pathway or non-cyclic photophosphorylation.

The electrons lost at PS II are replenished by a reaction involving water. Water splits in the presence of light. This is called photolysis. It happens at a system associated with PS II.



$$H_20 \rightarrow H^+ + 2e^- + O_2$$

The synthesis of ATP through cyclic or non-cyclic photophosphorylation is tied up to the hydrogen ion gradient. This mechanism of ATP production is called ***chemiosmosis.***

The products of light-dependent reactions are ATP and NADPH. Cyclic photophosphorylation produces ATP only. Non-cyclic photophosphorylation produces ATP and NADPH. The by-product is oxygen gas, which comes from water and is released into the atmosphere.

What you will do

Self–Test 4.1

Multiple Choice. Choose the letter of the best answer. Write the chosen letter on a separate sheet of paper.

1. Light-dependent reaction occurs in
   a. stroma
   b. thylakoid membrane
   c. thylakoid compartment
   d. intermembrane compartment

2. To store the energy of excited electrons is to pump Hydrogen ions from _____ and into _____
   a. outside the cell, stroma
   b. stroma, thylakoid compartment
   c. thylakoid compartment, stroma
   d. intermembrane compartment, outside the cell

3. The following are produced during light-dependent reaction **except**
   a. ATP
   b. sugar
   c. NADPH
   d. oxygen

4. The cyclic pathway of photophosphorylation produces
   a. ATP only
   b. NADPH only
   c. ATP and NADPH
   d. organic sugars only

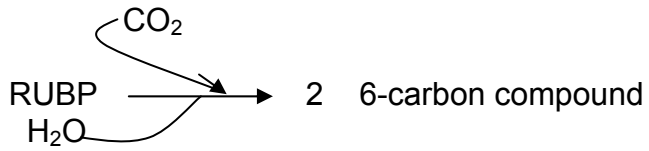
5. Which of the following replaces the electrons that escape from PS II?
   a. PS I
   b. NADPH
   c. splitting of water
   d. the three are correct

Key to answers on page 26.

Lesson 5. Light- Independent Reaction / Carbon Dioxide Fixation

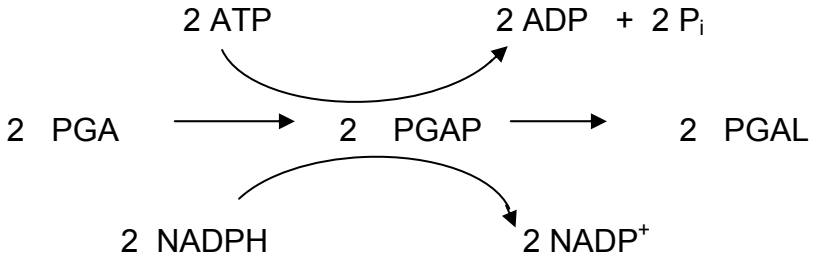
What do plants do with the products of light-dependent reaction – ATP and NADPH? These two substances are high-energy molecules. The energy could be harnessed in making food out of carbon dioxide. How do plants fix carbon dioxide into food?

First carbon dioxide enters the leaf through the stomata. It goes into the mesophyll layers and moves to the stroma of the chloroplast. Here, carbon dioxide collides with 5-carbon compound called **ribulose-1, 5-biphosphate (RUBP)** to yield 6-carbon-containing sugar. The process is catalyzed by RUBP carbonxylase.

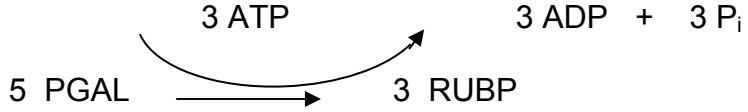


The 6-carbon compound is broken into two molecules of 3-carbon sugar, phosphoglycerate (PGA). This requires two molecules of ATP.

The 2 molecules of PGA are converted into 2 molecules of phosphoglyceraldehyde (PGAL), a 3-carbon compound. PGAL is the first stable product of photosynthesis. It needs 2 molecules of NADPH.



RUBP is regenerated from PGAL for the process to continue. A molecule of ATP is needed for the regeneration process.



The process occurs in a cyclic manner as shown in Figure 10. Since the first stable product is composed of 3 carbon atoms, it is called **C_3 Cycle**. Melvin Calvin unlocked this process. It is also named as ***Calvin Cycle***.

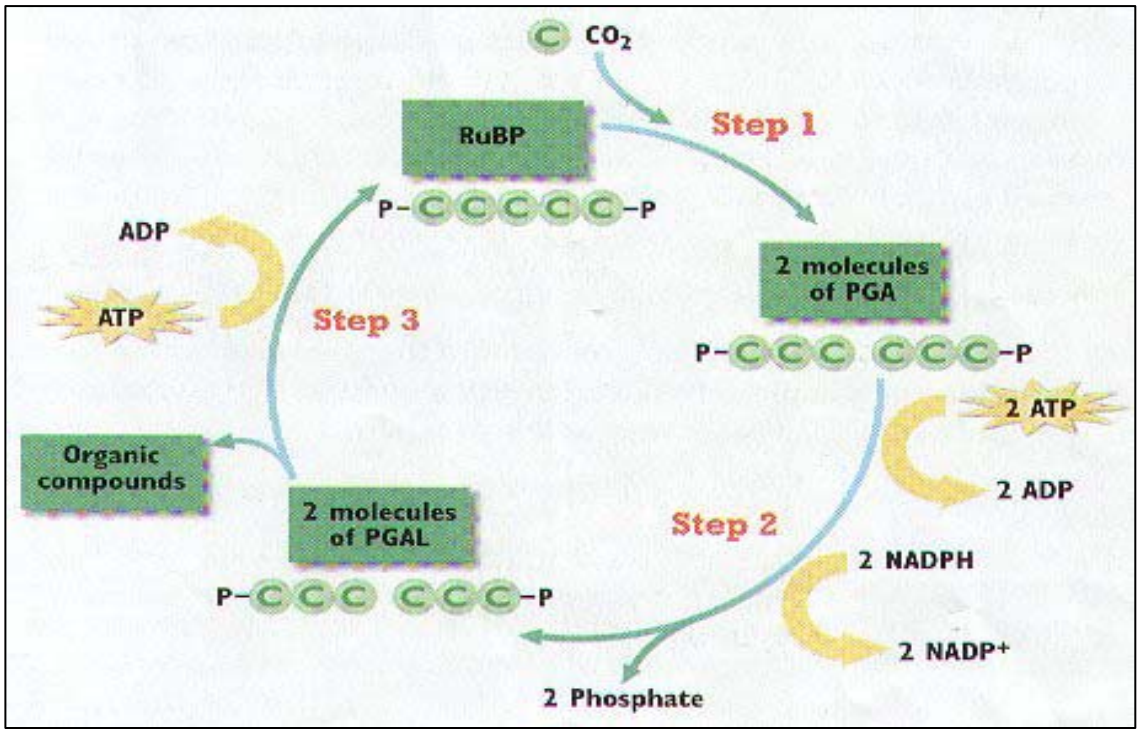


Figure 10. The Calvin Cycle

Three turns of Calvin Cycle are necessary to produce one net gain of PGAL. Five PGAL molecules are needed to regenerate 3 molecules of RUBP. The three turns use up 9 molecules of ATP and 6 molecules of NADPH.

PGAL is a substance used by plants to make other organic substances. An example of these organic substances synthesized by plants is glucose. To make one glucose molecule, a 6-carbon sugar, two molecules of PGAL are linked. This means six turns of Calvin cycle.

Challenge	Answer
If there are 6 rounds of Calvin Cycle,	
1. How many PGAL molecules are synthesized?	12 molecules
2. How many PGAL molecules are used to regenerate RUBP?	10 molecules
3. How many ATP molecules were used up to produce 1 glucose?	18 molecules
4. How many NADPH molecules were used up?	12 molecules

Do you understand now how the energy from the sun is utilized to produce the ATP and NADPH during the light-dependent reaction?

The light-independent reaction occurs during daytime, but light is not used directly.

What you will do

Self-Test 5.1

Multiple Choice. Choose the letter of the best answer. Write the chosen letter on a separate sheet of paper.

1. What is the point of entry of carbon dioxide into the inside of the leaves of plants?
   a. palisade layer
   b. spongy layer
   c. guard cells
   d. stomata

2. What substance is used to fix carbon dioxide during the light-independent reaction?
   a. Malate
   b. Oxaloacetate
   c. ribulose-1,5-biphosphate
   d. pyruvate

3. What enzyme catalyzes the reaction in question 2?
   a. Ribulose-1,5- biphosphate carboxylase
   b. Ribulose-1,5- biphosphate oxygenase
   c. Phosphoenolpyruvate carboxylase
   d. Protease

4. What is the first stable product of photosynthesis?
   a. PGA
   b. PGAL
   c. malate
   d. oxaloacetate

5. How many PGAL are used to regenerate three molecules of RUBP?
   a. 2
   b. 3
   c. 5
   d. 6

Key to answers on page 26.

From Lesson 2, we learned that stomata are present in the plant leaves especially at the underside. Water passes out and carbon dioxide enters the leaves through these openings. When the day is hot and dry, the stomata close to prevent water loss. The closure causes the build up of oxygen, but the available carbon dioxide is exhausted. When this happens, oxygen gas competes with carbon dioxide in reacting with RUBP. This produces a 2-carbon molecule. These 2-carbon molecules are broken down to carbon dioxide and water. We call this process as ***photorespiration***. Photorespiration makes photosynthesis inefficient because carbon dioxide is not fixed and ATP molecules are used up.

To escape photorespiration, alternative ways of fixing carbon dioxide evolved in plants. One pathway is called C_4 cycle. Carbon dioxide interacts with phosphoenolpyruvate (PEP) to form oxaloacetate, a 4-carbon compound. The process is catalyzed by phosphoenolpyruvate carboxylase.

Oxaloacetate is converted to malate, also a 4-carbon compund. Malate is pumped into the bundle sheath cells. Once here, carbon dioxide is released from malate.

Malate ---------- PEP + CO_2

Free carbon dioxide enters Calvin Cycle. This process requires additional 12 ATP molecules to produce one glucose molecule.

What will happen to PEP? It will go back to mesophyll cells to pick up another carbon dioxide to repeat the cycle.

Many tropical grasses are C_4 plants. Good examples of C_4 plants are crabgrass, sugarcane, corn and Bermuda grass.

Another alternative way of fixing carbon dioxide has evolved in plants found in arid regions such desert biome. Plants found in desert biomes belong to the family of Crassulaceae, flowering succulent (water-laden). They fix carbon dioxide when the stomata are closed.

PEP + CO_2 --→ 4 – carbon compound

Examples of 4- carbon compounds are oxaloacetate and malate. These 4-Carbon compounds are stored in large vacuoles in the mesophyll cells.

During the day, the stomata close. There is minimal loss of water but no CO_2. So, the stored 4-Carbon compounds release CO_2 to Calvin Cycle to produce sugars. This adaptation is called crassulacean acid metabolism (CAM). Plants that use CAM mechanism of fixing CO_2 are called CAM plants. Many epiphytes (hanging) and desert plants are CAM plants. Good examples are pineapple and cactus.

This information is very important to agriculture and in landscaping business. Farm owners and landscaping business operators would know what plants to be planted in shaded and well-lighted area.

What you will do

Self-Test 5.2

Multiple Choice. Choose the letter of the best answer. Write the chosen letter on a separate sheet of paper.

1. Plants evolved alternative ways of fixing CO_2. Why?
   a. Oxygen gas at high temperature competes with CO_2 in reacting with RUBP.
   b. Most photosynthetic plants are present in hot areas.
   c. The C_3 cycle is not very efficient in making food.
   d. The C_4 cycle and CAM are very efficient.

2. When do CAM plants utilize CO_2 to make sugar?
   a. daytime
   b. nighttime
   c. anytime

3. Which of the following uses C_3 Cycle in making sugar?
   a. pineapple
   b. crabgrass
   c. cactus
   d. barley

4. Which of the following conditions leads to the adaptation of C4 and CAM pathways?
   a. high CO_2 and low O_2
   b. low O_2 and High CO_2
   c. low CO_2 and high O_2
   d. low CO_2 and low O_2

5. Which of the following pathways produces PGAL as precursor to carbohydrate synthesis?
   a. C_3
   b. C_4
   d. CAM

Key to answers on page 26.

Let's Summarize

1. Organisms that make food are called producers or autotroph. Autotrophs may be photosynthetic or chemosynthetic.
2. Photosynthetic autotrophs use solar radiation to make food.
3. Not all components of solar energy is needed in photosynthesis. Photosynthesis uses only the visible light.
4. Plant contains pigments that trap energy from the sun. These pigments form clusters called photosystems.
5. There are two photosystems – PS I and PS II. Photosystems are light harvesting antenna composed of
   - several 100 chlorophyll a & b molecules, and carotenoids
   - a central chlorophyll molecule (P680 or P700)
   - specialized molecule called the primary electron acceptor
6. These pigments are found in the chloroplast. Chloroplasts are found in the leaves of plant. They are found in the guard cell and mesophyll cells.
7. There are two stages of photosynthesis – light dependent reaction and light-independent reaction.
8. Light-dependent reaction produces ATP and NADPH
9. ATP and NADPH are used in the fixation of carbon dioxide, a light-independent reaction.
10. There are three ways of fixing CO_2 namely, C_3 cycle, C_4 cycle and CAM.
11. Due to the three pathways of carbon dioxide fixation, there are three kinds of plants namely, C_3 plants, C_4 plants and CAM plants

Posttest

Multiple Choice. Choose the letter of the best answer. Write the chosen letter on a separate sheet of paper.

1. What do we need in order to do work?
   a. work place
   b. people
   c. equipment
   d. energy

2. What do we call organisms that make food?
   a. photosynthetic
   b. chemosynthetic
   c. consumers
   d. a and b

3. Which of the following molecules is very energetic?
   a. vitamins
   b. nucleic acid
   c. coenzyme
   d. adenosine triphosphate

4. Which ray of light has the longest wavelength?
   a. blue
   b. indigo
   c. orange
   d. red

5. Which ray of light is most energetic?
   a. blue
   b. indigo
   c. orange
   d. red

6. Where does the oxygen gas released during photosynthesis come from?
   a. water
   b. sugar
   c. pigments
   d. carbon dioxide

7. Disk-shaped structures with photosynthetic pigments are known as
   a. thylakoid
   b. granum
   c. chloroplast
   d. stomata

8. What are the most common group of photosynthetic pigments in plants?
   a. anthocyamin
   b. chlorophyll a
   c. chlorophyll b
   d. chlorophyll c

9. Stroma are gel-like matrix (a solution) that surrounds the
   a. chloroplast
   b. chlorophyll
   c. granum
   d. none of the three

10. Which of the following substances is produced through cyclic phosphorylation?
    a. ATP only
    b. NADPH only
    c. ATP and NADPH
    d. sugar

11. Plants that use only the Calvin Cycle for photosynthesis are called
    a. C_3 plants
    b. C_4 plants
    c. CAM plants
    d. all three of them

12. CAM Plants can survive in dry, hot deserts because they can fix carbon at
    a. daytime
    b. nighttime
    c. any time

13. Which of the following is the by-product of photosynthesis?
    a. water
    b. sugar
    c. oxygen
    d. carbon dioxide

14. Photosynthesis occurs in what organelle of plants and algae?
    a. plasma membrane
    b. mitochondrion
    c. lysosome
    d. chloroplast

15. What are the light collecting units of the chloroplast?
    a. pigments
    b. photosystem
    c. stroma
    d. membranes

16. A friend asks which of the following plants should be planted in a well-lighted area. What is your answer?
    a. rice
    b. onion
    c. cattleya
    d. bermuda grass

17. Carbon fixing reactions occur in a pathway called the
    a. light-dependent reaction
    b. light-independent reaction

18. Folded thylakoids that resemble stacks of pancakes are called
    a. stroma
    b. stromal lamella
    c. granum
    d. none of them

19. A five-carbon carbohydrate in the Calvin cycle is
    a. PGAL
    b. PGA
    c. RUBP

20. A three-carbon molecule in the Calvin cycle is
    a. RUBP
    b. malate
    c. PGAL

21. How many PGALs are needed to make one molecule of glucose?
    a. 1
    b. 2
    c. 3
    d. 4

Key to answers on page 27.

Key to Answers

Pretest

1. c
2. a
3. d
4. c
5. c
6. d
7. c
8. a
9. b
10. c
11. c
12. d
13. b
14. a
15. c
16. c
17. b
18. d
19. d
20. d

Lesson 1

Activity 1.1

A rainbow was observed when light passed through the prism. This means that the visible light is composed of many colors of light.

Self-Test 1.1

1. d
2. c
3. b

Lesson 2

Activity 2.1

Only parts of the leaf that turn blue-black. This means that these parts manufactured food.

Self-Test 2.1

1. c
2. c
3. a
4. b
5. c

Lesson 3

Self-Test 3.1

1. b
2. a
3. d
4. b
5. c
6. c

Lesson 4

Self-Test 4.1

1. c
2. c
3. b
4. a
5. c

Lesson 5

Self-Test 5.1

1. d
2. c
3. a
4. b
5. c

Self-Test 5.2

1. a
2. a
3. d
4. c
5. a

Posttest

1. d	6. a	11. a	16. d
2. d	7. a	12. b	17. b
3. d	8. c	13. c	18. c
4. d	9. c	14. d	19. c
5. a	10. a	15. c	20. c
			21. b

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