Photosynthesis & Cellular Respiration


Photosynthesis
© Amy Brown Science

THE IMPORTANCE OF FOOD

Food provides living things with the: chemical building blocks they need to grow and reproduce.

Food serves as a source of __energy__.

Food serves as a source of…
…raw materials for the cells of the body.

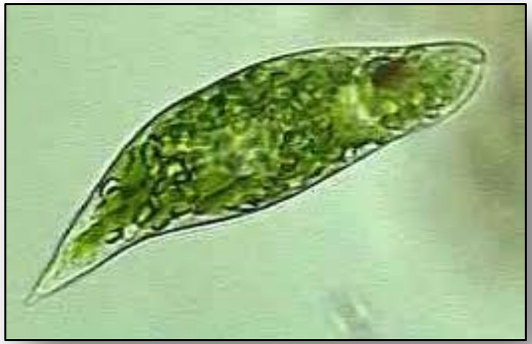
Autotrophs and Heterotrophs

All life on Earth depends on the flow of energy through the ecosystem. The source of this energy is the sun.

Autotrophs

Autotrophs are organisms that can make their own food.

These organisms use the _light energy_ from the sun to produce food in the form of _glucose or sugar_.



This includes all green plants, some bacteria, and some protists.

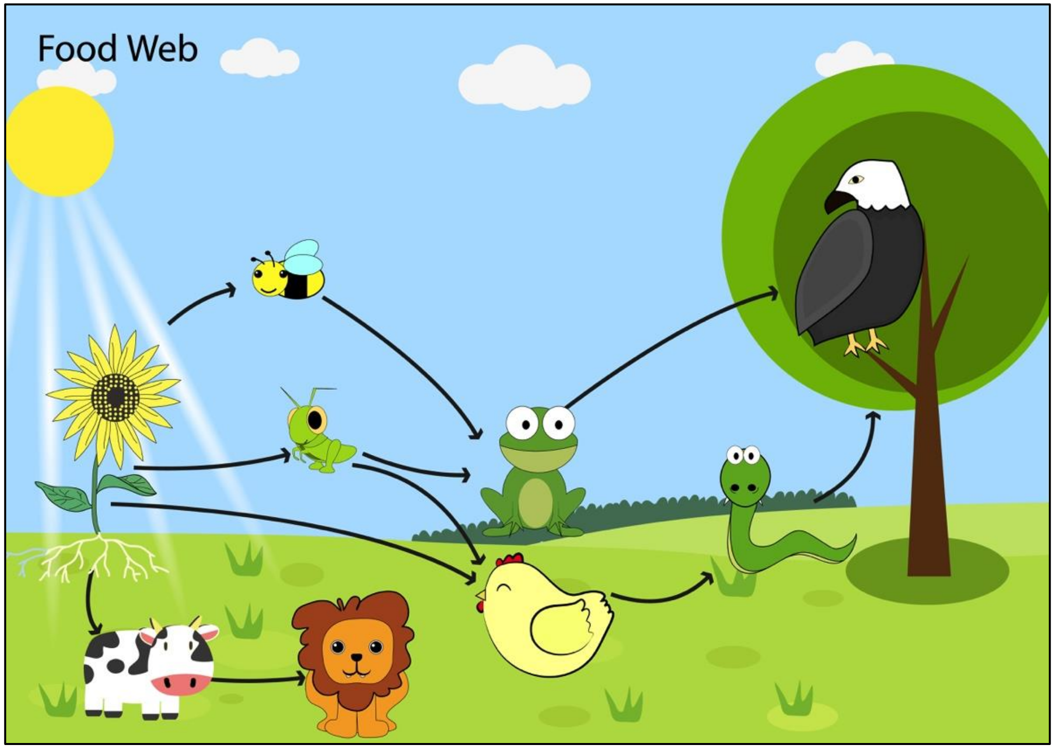
Heterotrophs

These are organisms that cannot make their own food.

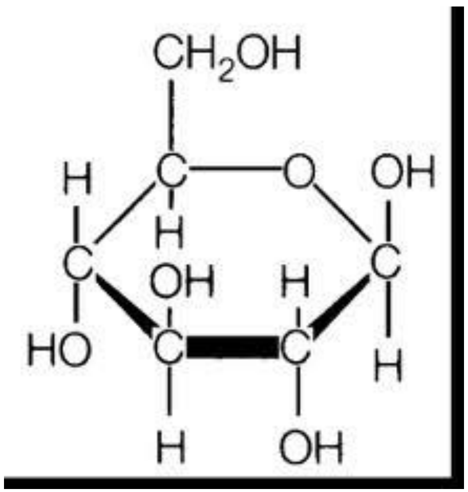
Examples are all animals and all fungi.

Heterotrophs must consume food. Heterotrophs eat plants or eat other animals that eat plants.

Energy enters the ecosystem in the form of sunlight . Plants use the sun's energy to make glucose . The sun's energy is stored in the molecule of glucose. The energy moves up the food chain when a consumer eats the plant.



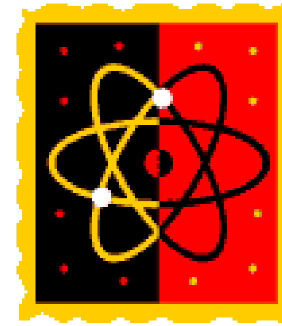
Glucose



Photosynthesis is converting radiant energy from the sun into chemical energy in the form of glucose.

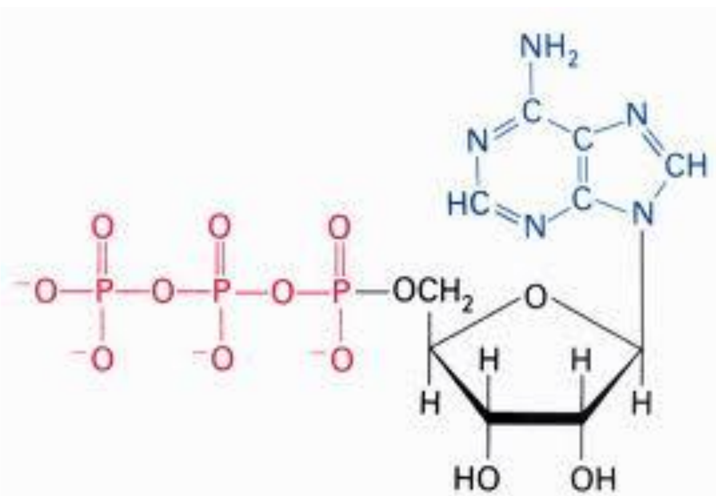
Chemical Energy and ATP

Inside living cells, energy can be stored in chemical compounds.



One of the principal chemical compounds that cells use to store and release energy is:

ADP / ATP

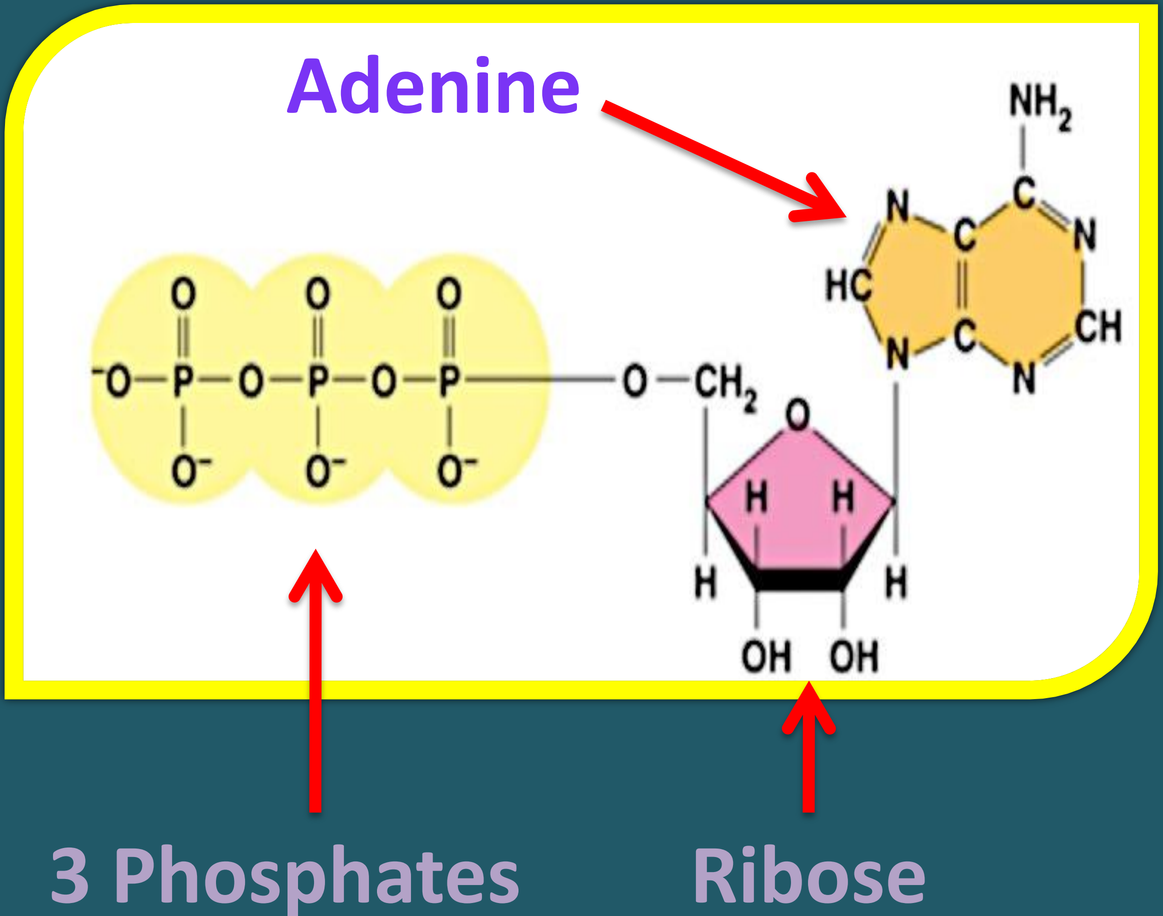


ATP - Adenosine Triphosphate

ADP - Adenosine Diphosphate

ADP is energy poor (like a dead battery.)	ATP is energy rich (like a charged battery.)

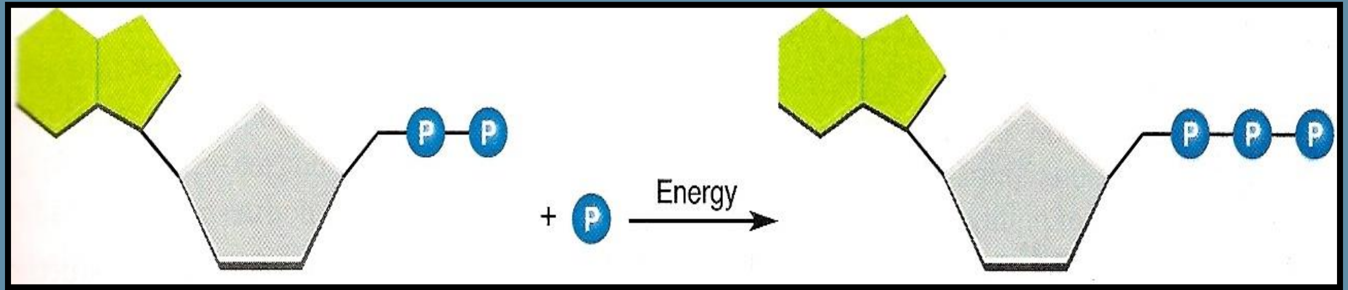
Structure of ATP



Consists of:

- Adenine, a nitrogen base
- Ribose, a five-carbon sugar
- A chain of three phosphate groups

How ADP Becomes ATP



ADP is a compound that looks almost like ATP. The difference is that….

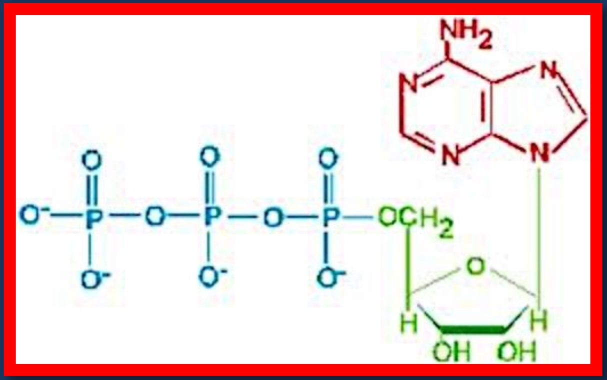
…ADP has 2 phosphate groups and ATP has three phosphate groups.

When a cell has energy available, it can store small amounts of it by adding a phosphate group to ADP.

Adding a phosphate to ADP forms a molecule of ATP. The addition of the third phosphate stores energy.

When a cell needs energy, the third phosphate will be removed. This releases energy.

ATP has enough stored energy to power a variety of cellular activities such as…..



1. Photosynthesis
2. Protein synthesis
3. Muscle contraction
4. Active transport across the cell membrane

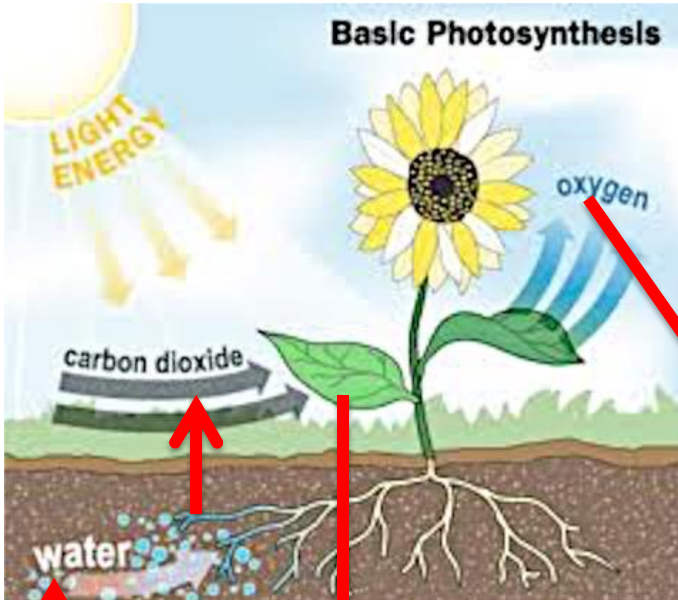
The ATP molecule is the _basic energy source_ of all living cells.

In a cell, ATP is used continuously and must be regenerated continuously. In a working muscle cell, 10 million ATP are consumed and regenerated per sec.

And now for an earworm…

- https://www.youtube.com/watch?v=aupr9qT2qgc

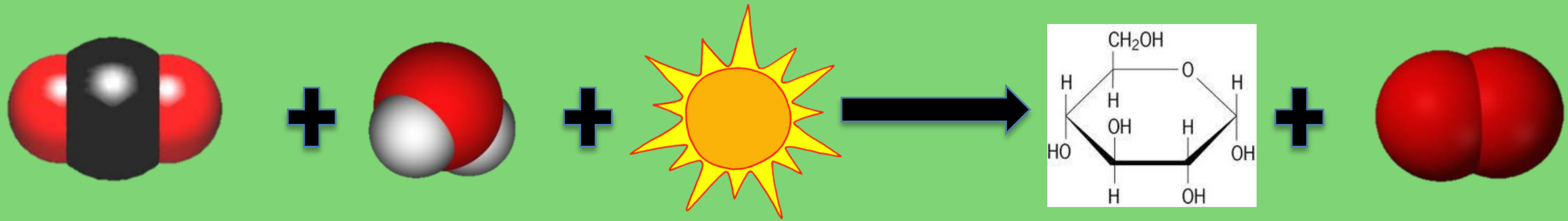
Overview of Photosynthesis



In photosynthesis, plants use the energy of the sun to convert water and carbon dioxide into high-energy sugar molecules.

Oxygen is given off as a waste product.

Life on earth is dependent on photosynthesis for food and oxygen.

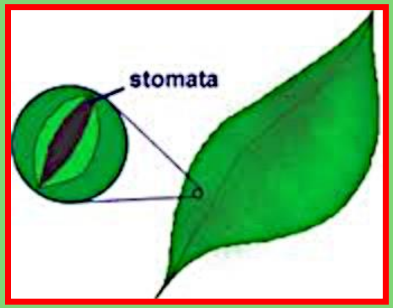


The Photosynthesis Equation

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

Photosynthesis uses the energy of sunlight to convert water and carbon dioxide into high-energy sugars (glucose) and oxygen.

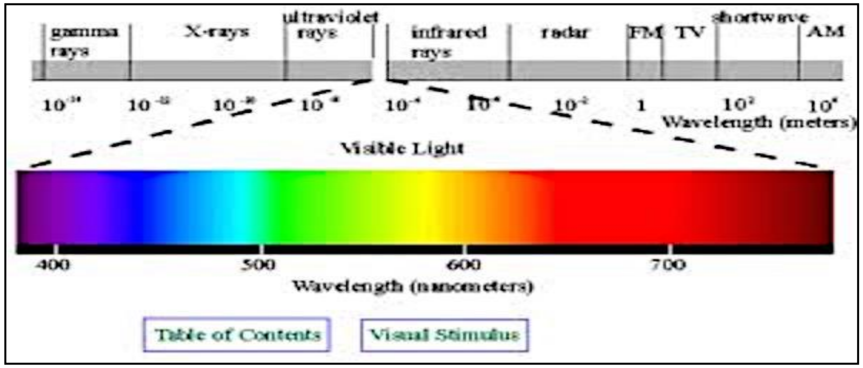
The carbon dioxide is found in the atmosphere and is taken in by the leaves of the plant.



The water is in the ground and is absorbed by the roots of the plant.

Chlorophyll and Other Pigments

Pigment: Any substance that absorbs light. Different pigments absorb light of different wavelengths.

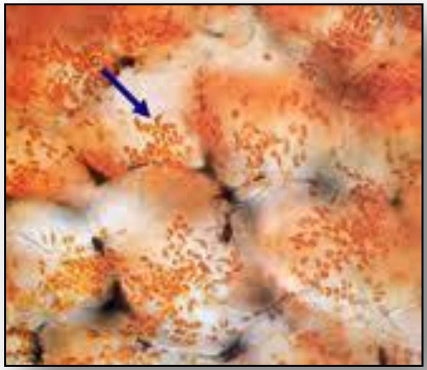


Plants absorb the sun's energy with light absorbing pigments.

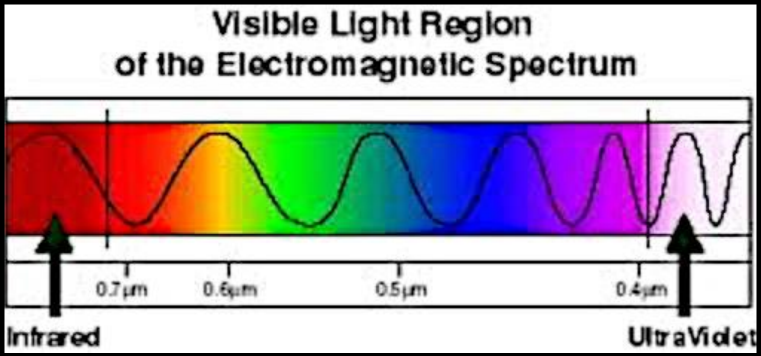
Chloroplasts:

Contains the green pigment chlorophyll.

Chromoplasts:



Contains the pigments of other colors.

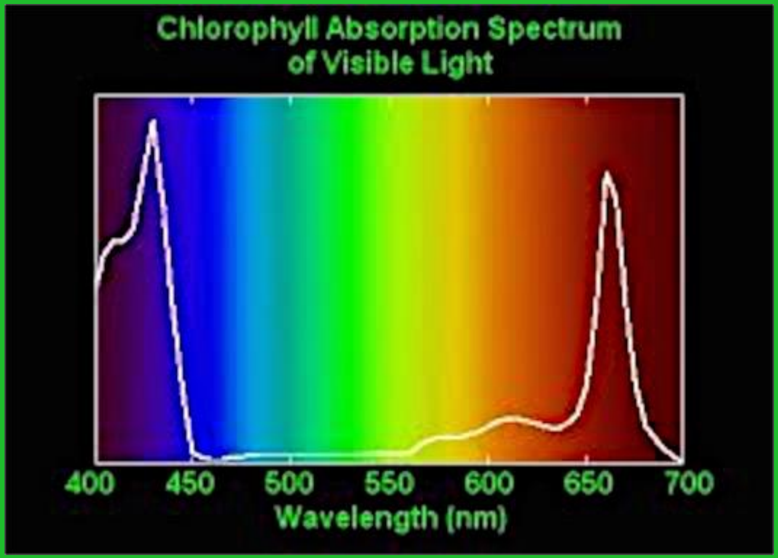


The colors of the visible spectrum are:

red, orange, yellow, green, blue, indigo, and violet.

Different pigments absorb light of different wavelengths, and the wavelengths that are absorbed disappear.

The colors we see are the wavelengths of light that a being _reflected_ by a pigment instead of being absorbed.



Chlorophyll is able to absorb all of the colors of the spectrum except **green**. Chlorophyll reflects green light; therefore chlorophyll appears green to our eye.

There are two main kinds of chlorophyll:

a) chlorophyll-a: blue - green
b) chlorophyll-b: yellow - green

What wavelengths of light are best absorbed by chlorophyll? Around 425 nm and 660 nm

What wavelengths of light are least absorbed by chlorophyll? Around 450 nm to 650 nm

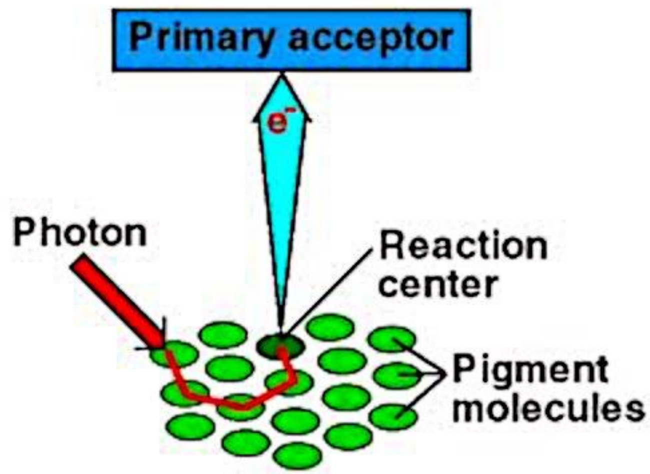
Why does chlorophyll-a appear to be blue-green in color?

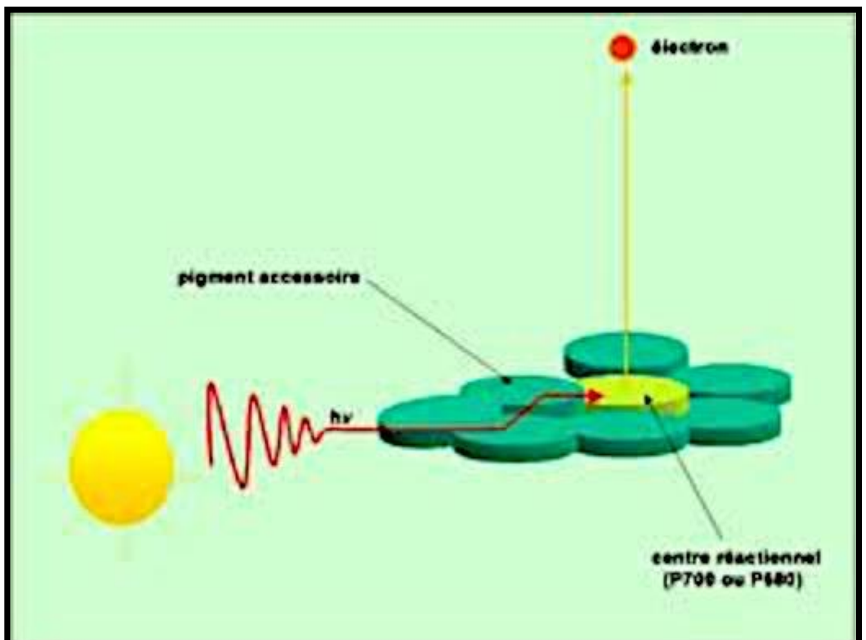
It is reflecting the wavelengths of light between 450 and 550 nm.

Why does chlorophyll-b appear to be yellow-green in color?

It is reflecting the wavelengths of light between 550 and 650 nm.

When chlorophyll absorbs light, energy is transferred directly to electrons in the chlorophyll molecule.

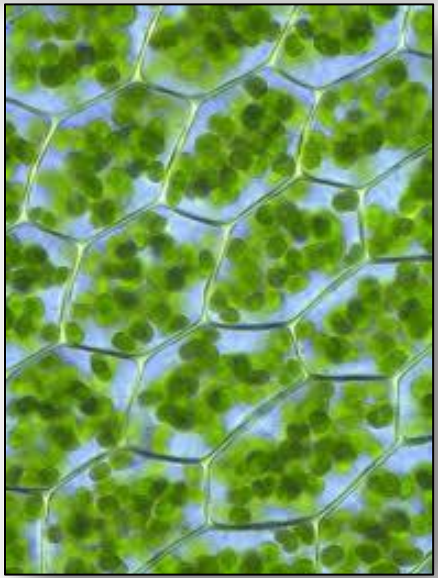




This raises the energy level of these electrons. These high-energy electrons make photosynthesis work.

Leaves are the major organs of photosynthesis.

There are about half a million chloroplasts per square millimeter of leaf surface.



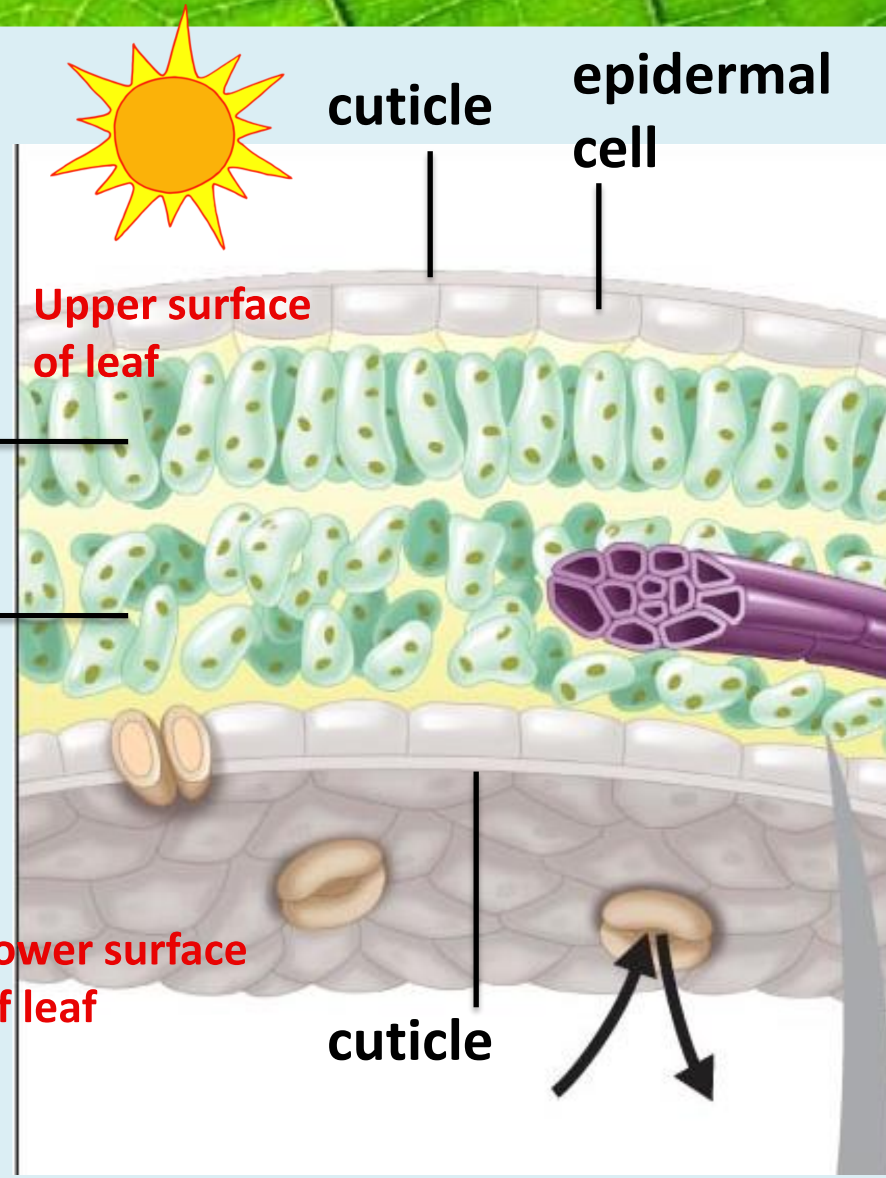
Leaf Structure

Cuticle:

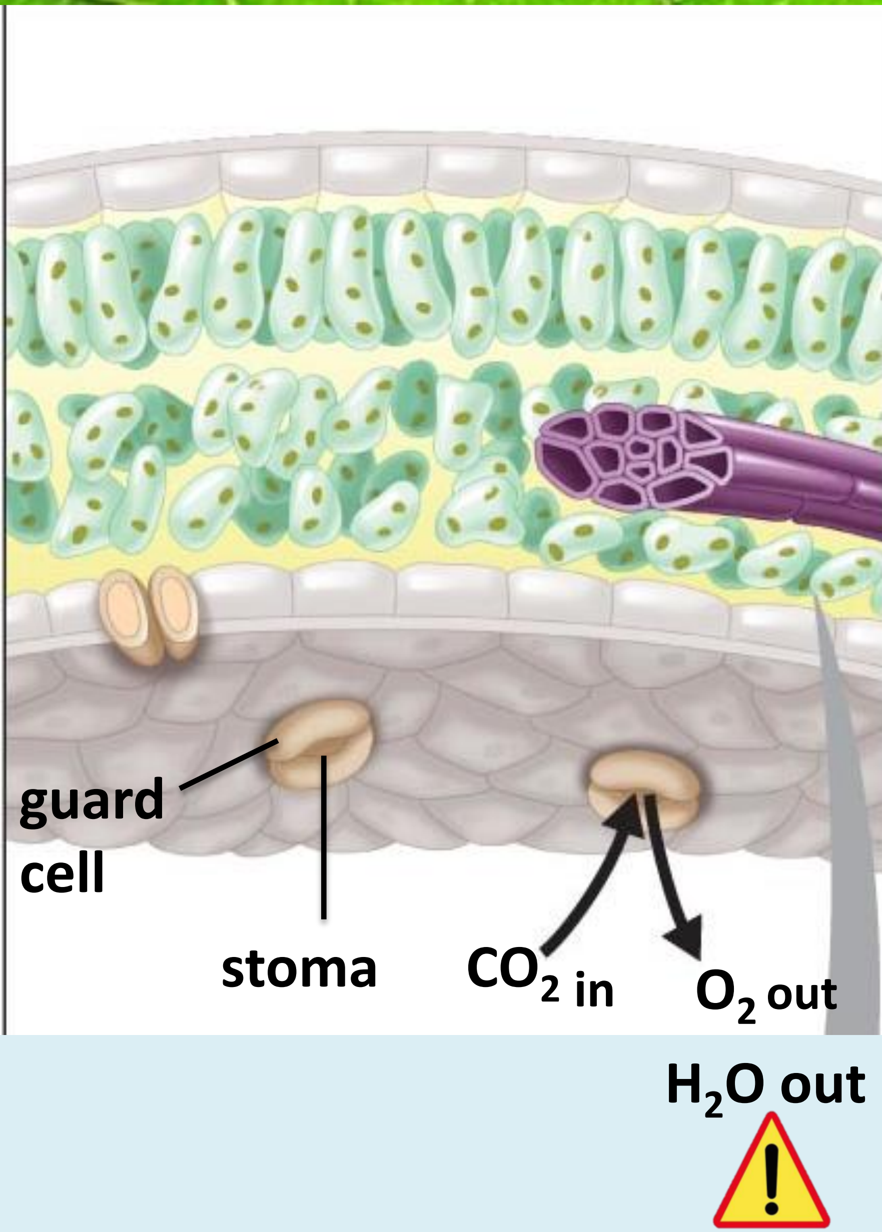
A waxy covering on the upper and lower surface that helps to prevent water loss from the leaf.

Mesophyll:

- The middle area of the leaf.
- Composed of palisade cells and spongy cells.
- Both types of cells contain many chloroplasts.
- The palisade layer is the primary photosynthetic layer of the leaf.



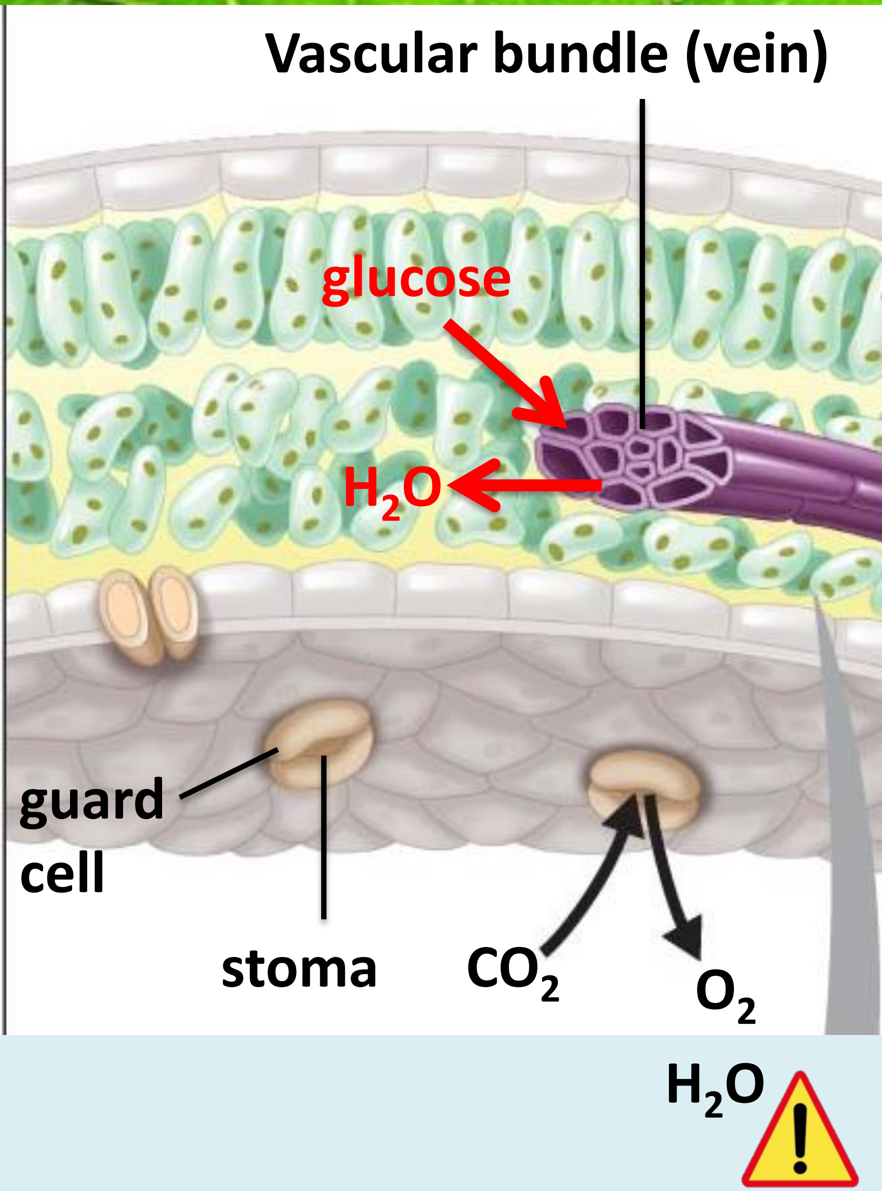
Leaf Structure



Stomata:

1. Pores on the underside of the leaf through which carbon dioxide enters the leaf and oxygen exits the leaf.
2. The stoma is the opening into the leaf.
3. Guard cells are found on either side of a stoma. Their function is to open and close the stoma.
4. This is a source of water loss from the plant.
5. The stomata must open to let carbon dioxide into the leaf, but when they are open, water will escape the leaf.
6. Stomata are usually only found on the lower surface. This helps to reduce water loss.

Leaf Structure



Vascular Bundle (Vein):

1. Contains Xylem and Phloem.

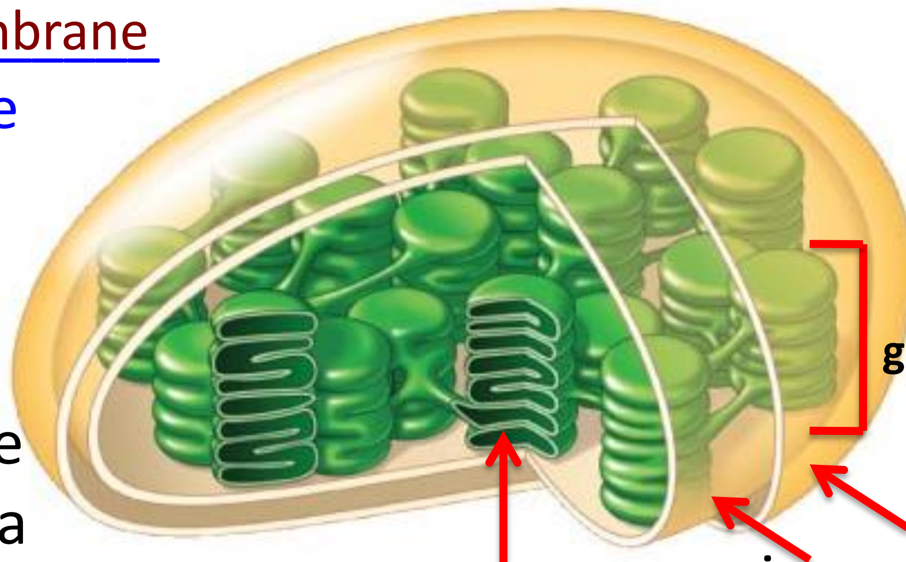
2. Xylem carries water up the plant. Water is brought to the leaf through the xylem.

3. Phloem carries food down the plant. The glucose being made will exit the leaf through the phloem and will be carried to other parts of the plant.

The Structure of the Chloroplast

It has a double membrane separated by a space between the two membranes.

The thylakoids, in the interior of the chloroplasts, make a third membrane system.

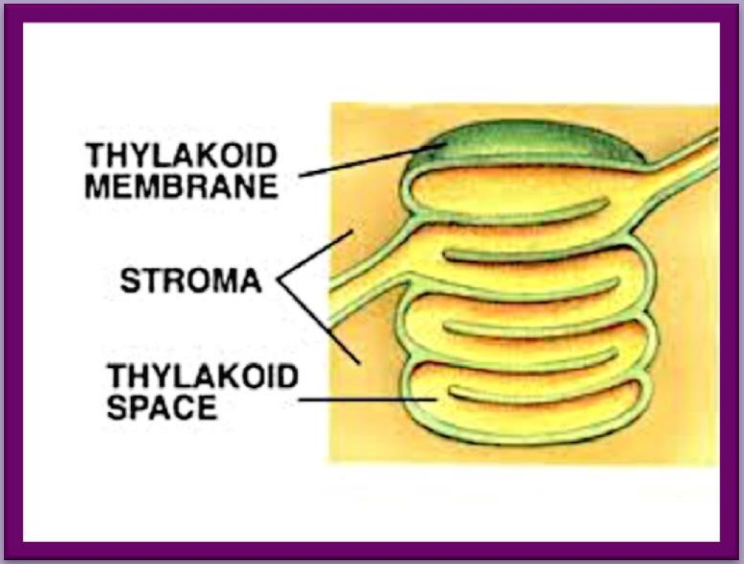


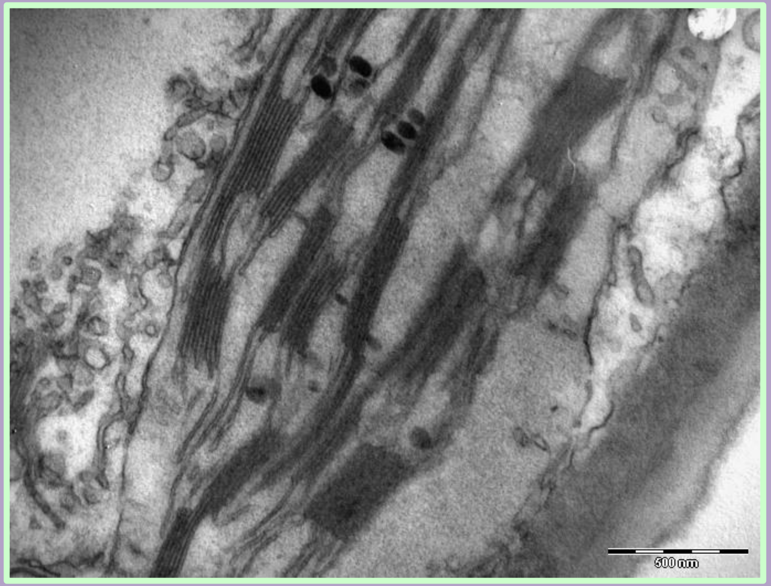
Big stacks of thylakoids are called grana.

Thylakoids contain chlorophyll.

Surrounding the thylakoids is a dense solution called the stroma.

The Thylakoids



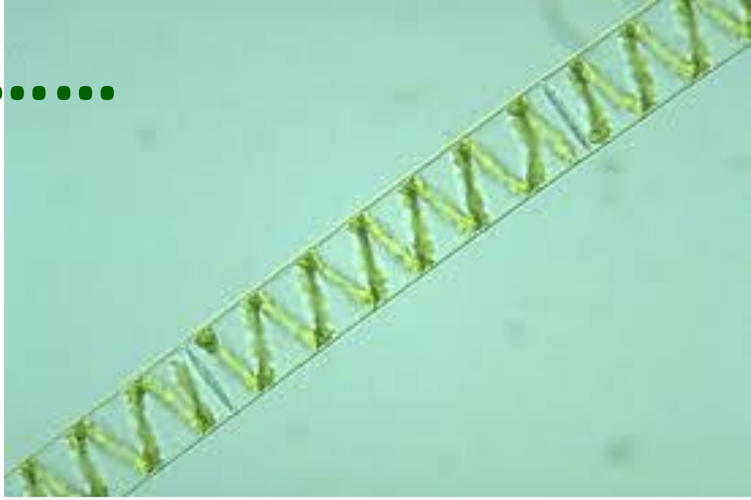


Thylakoid: the structural unit of photosynthesis.

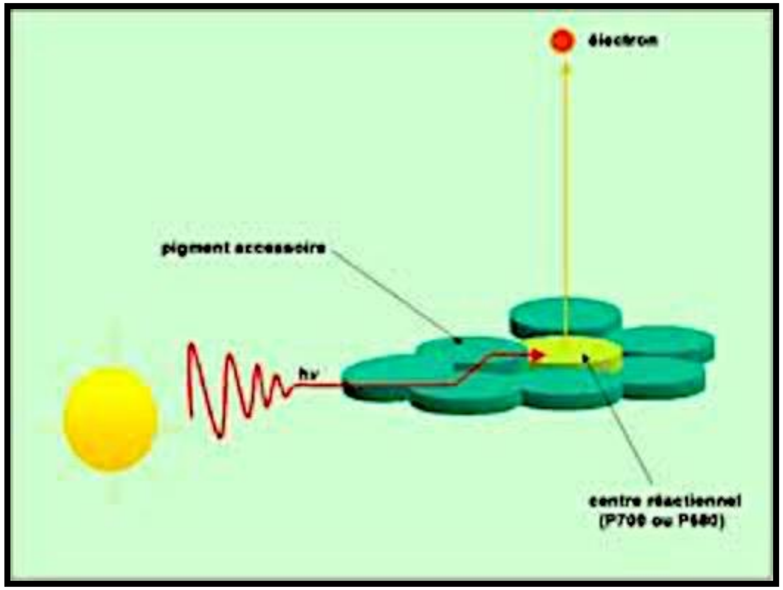
The thylakoids take the form of flattened sacs or vesicles.

Chlorophyll molecules are built into the thylakoid membrane.
These chlorophyll molecules capture the light energy from the sun.

Inside the chloroplast……



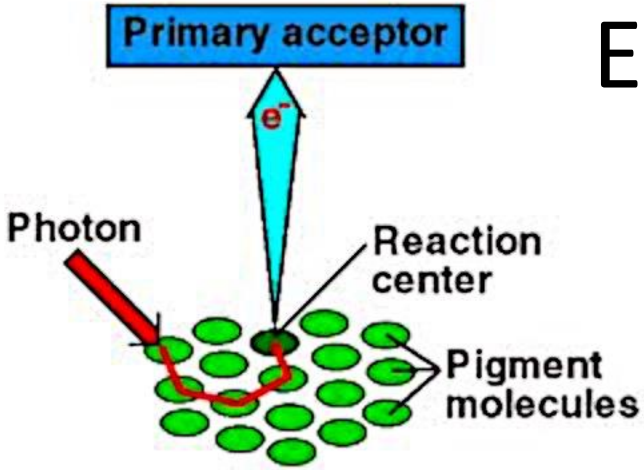
Photosynthesis takes place inside the chloroplasts.



Chlorophylls and other pigments are clustered together and embedded in the thylakoid membrane.

These clusters of pigments are called _photosystems_.
These are the _light collecting units_ of the chloroplast.

Electron Carriers

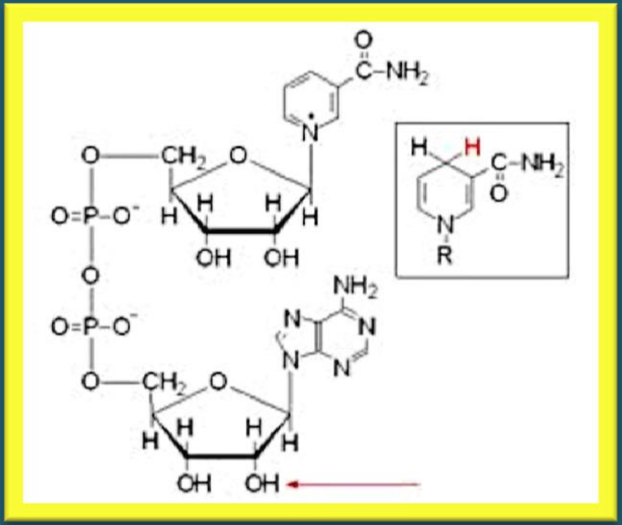


When sunlight hits the molecules of chlorophyll, the _electrons_ in the chlorophyll molecules become very excited_.

Excited electrons are electrons that have gained a great deal of energy.

These high-energy electrons need a _carrier_. Cells use electron carriers to transport _high-energy electrons_ from chlorophyll to other molecules.

An electron carrier is a compound that can accept a pair of high-energy electrons and transfer them along with most of their energy to another molecule. This process is called _electron transport_ and the electrons carriers are known as the_electron transport chain_.



One of these electron carriers is known as NADP+.

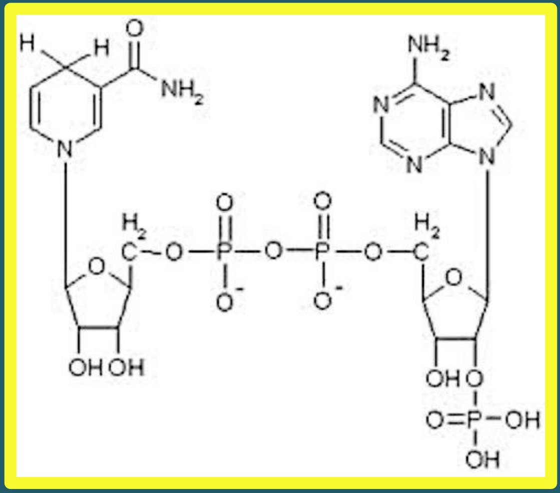
NADP+ accepts and holds:

2 high-energy electrons along with a hydrogen ion (H^+).

This converts NADP+ into NADPH.

NADPH will carry these high-energy electrons to chemical reactions elsewhere in the chloroplast.

These high-energy electrons will be used to build molecules of glucose.



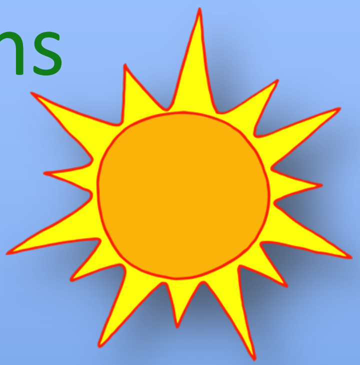
Oh, look! Another earworm!

- https://www.youtube.com/watch?v=2kfb-e6Y7as

The Stages of Photosynthesis - An Overview

Photosynthesis takes place in two stages:

The Light Dependent Reactions



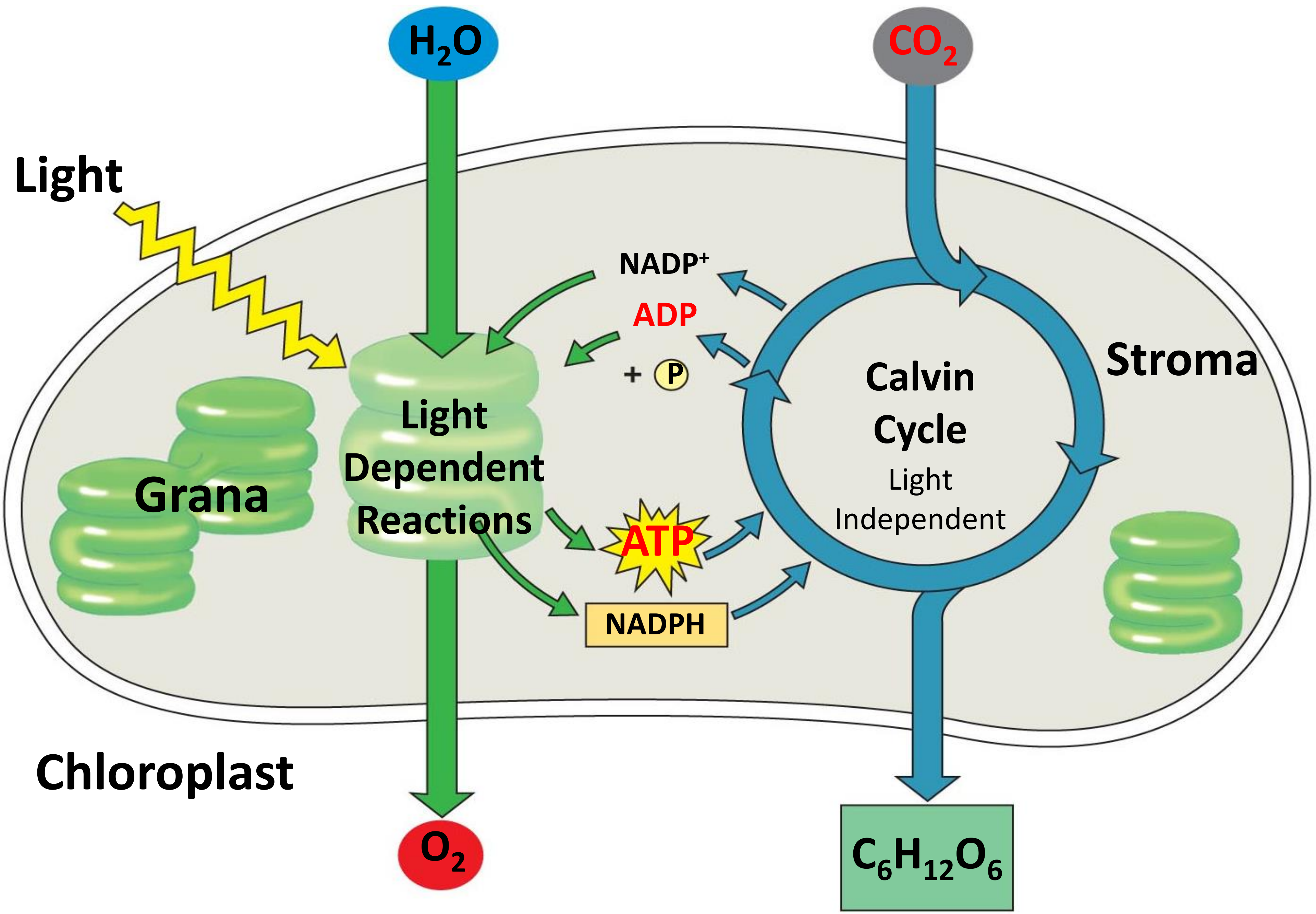
The light dependent reactions takes place within the thylakoid membranes.

The Light Independent Reactions

Also called the dark reaction.

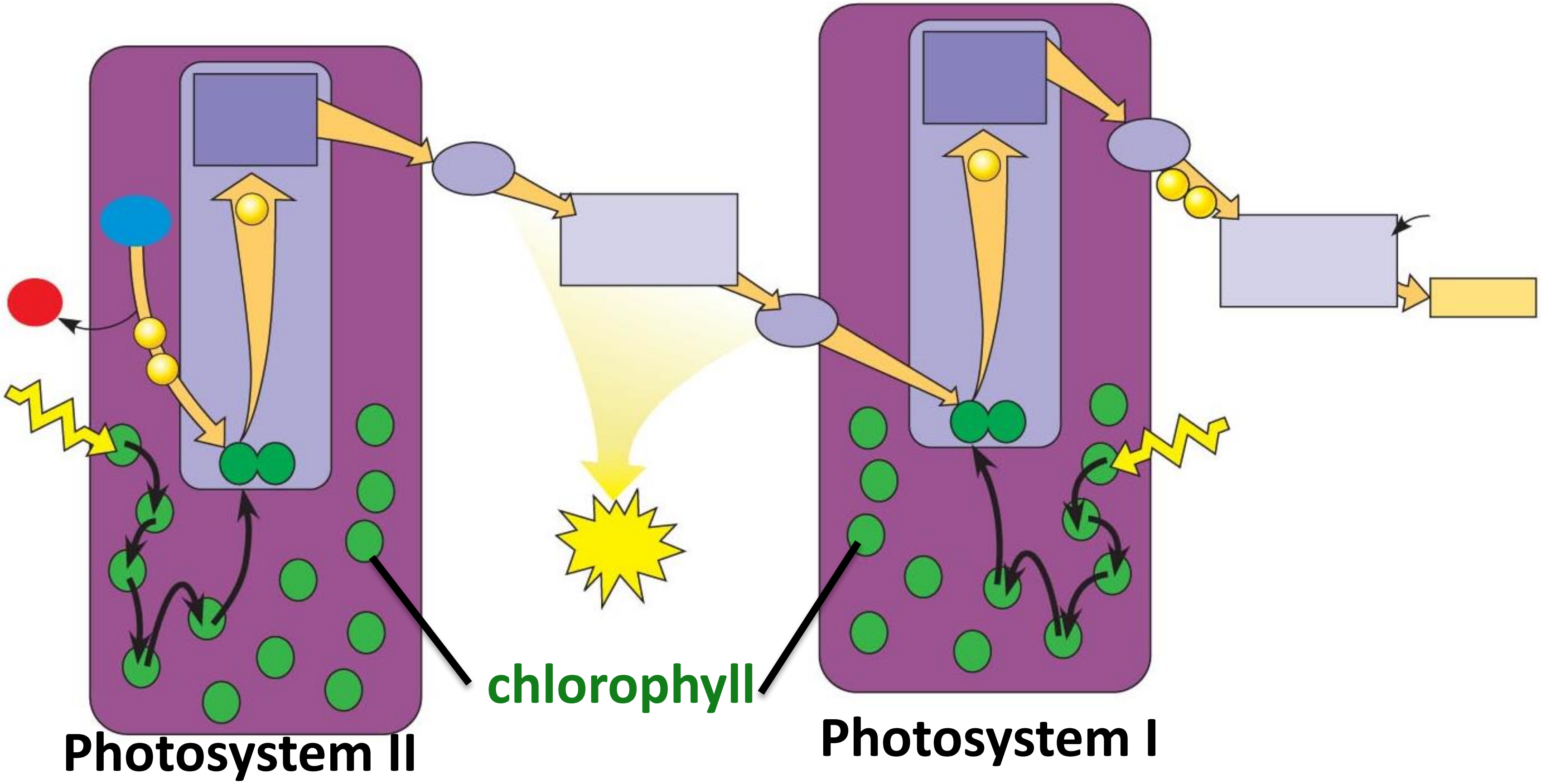
Also called the Calvin cycle.

The light independent reactions takes place in the: stroma - the region outside of the thylakoids.



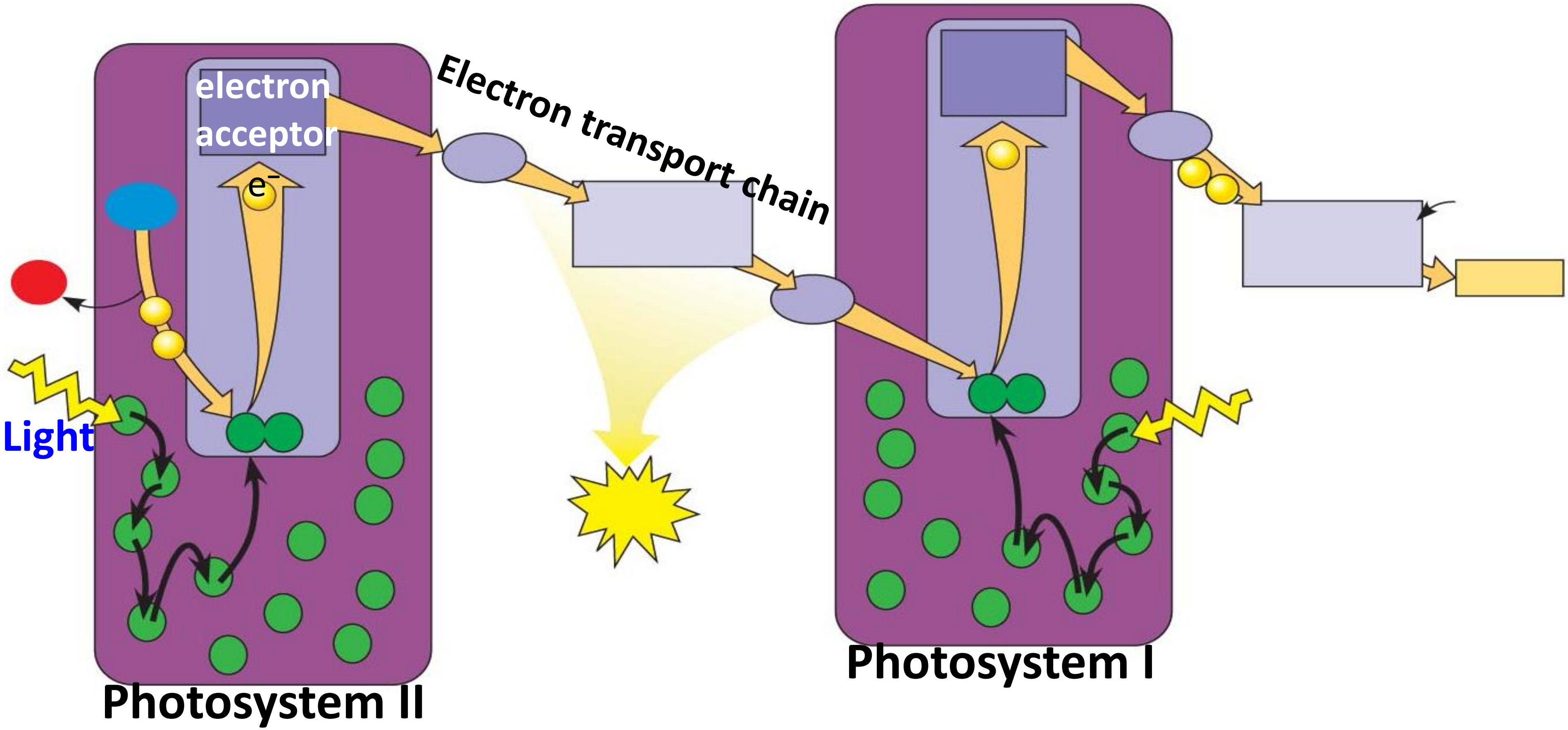
H_2O
CO_2
Light
$NADP^+$
ADP
+ P
Calvin
Cycle
Light
Independent
Stroma
Light
Dependent
Reactions
Grana
ATP
NADPH
Chloroplast
O_2
$C_6H_{12}O_6$

The Light Dependent Reactions – The Light Reaction – A Look at the Photosystems



First, let's label each photosystem. There are two photosystems: photosystem I and photosystem II.

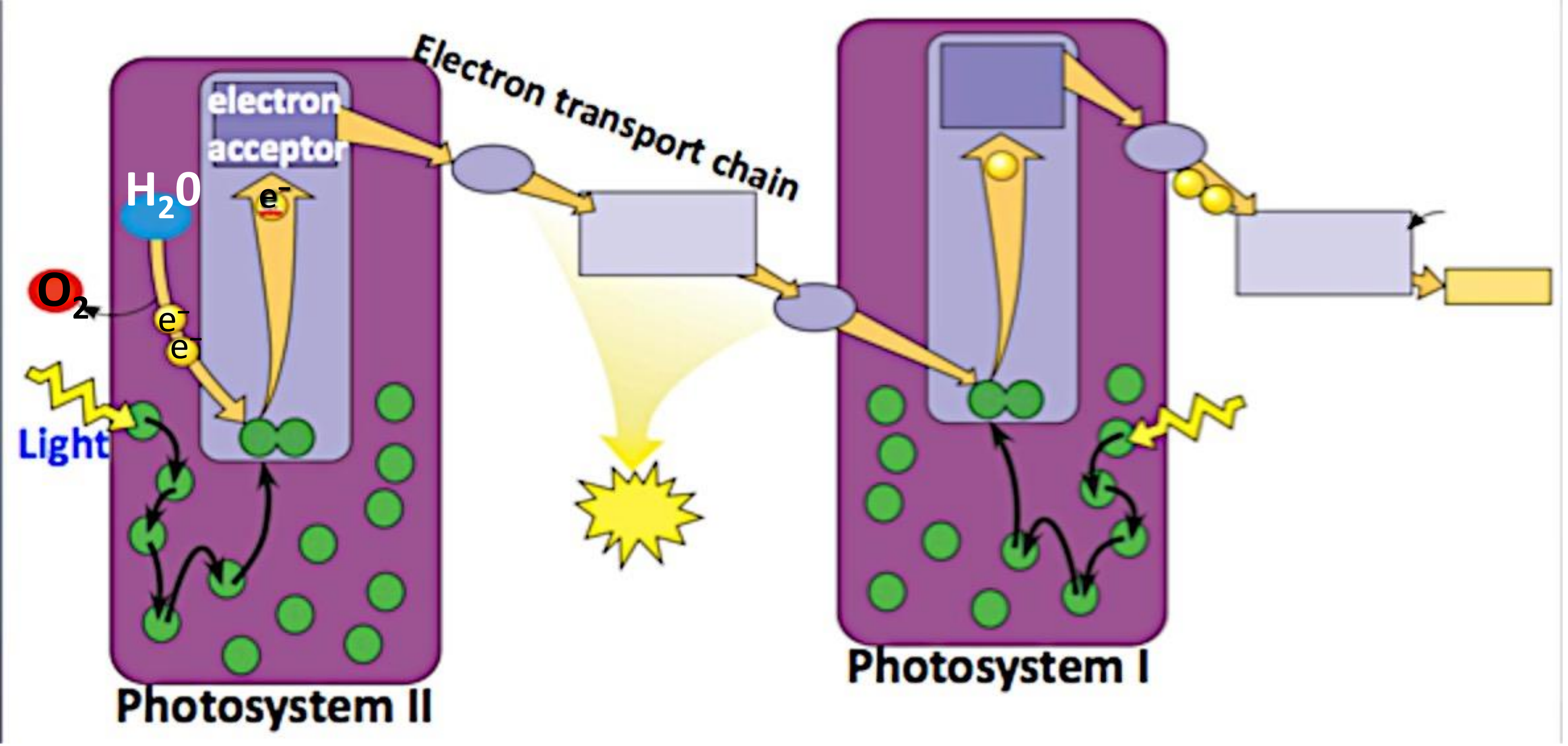
Photosystem: A collection of pigment molecules (chlorophyll) that serve as the light collecting unit.



Pigments in photosystem II absorb light.

This light energy is absorbed by chlorophyll’s <u>electrons</u>, increasing their energy level.

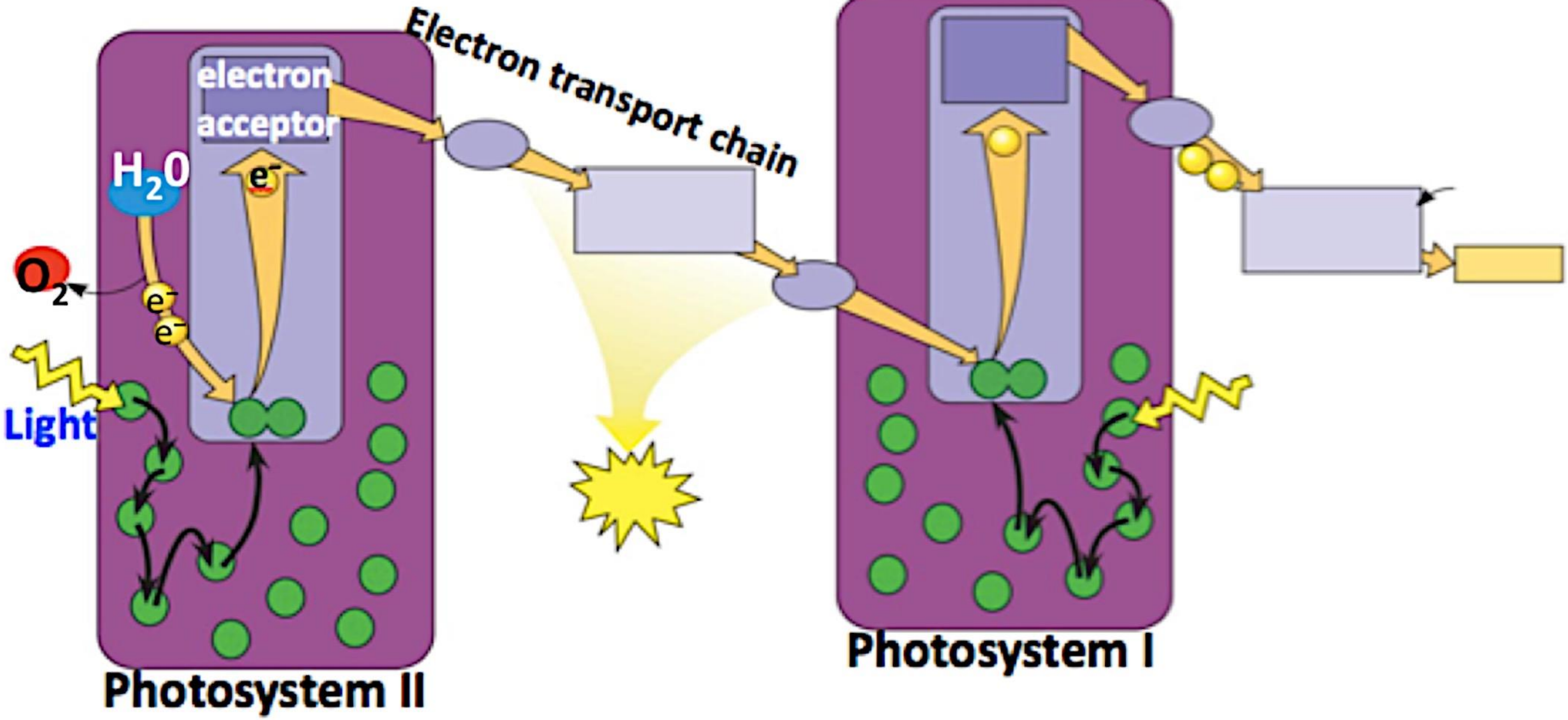
These high-energy electrons are passed to the <u>electron transport chain</u>.



The electrons that were _lost_ must now be _replaced_.

Enzymes in the thylakoid membrane break apart _water_ molecules into _2 electrons, 2 H^+ ions, and 1 oxygen atom_.

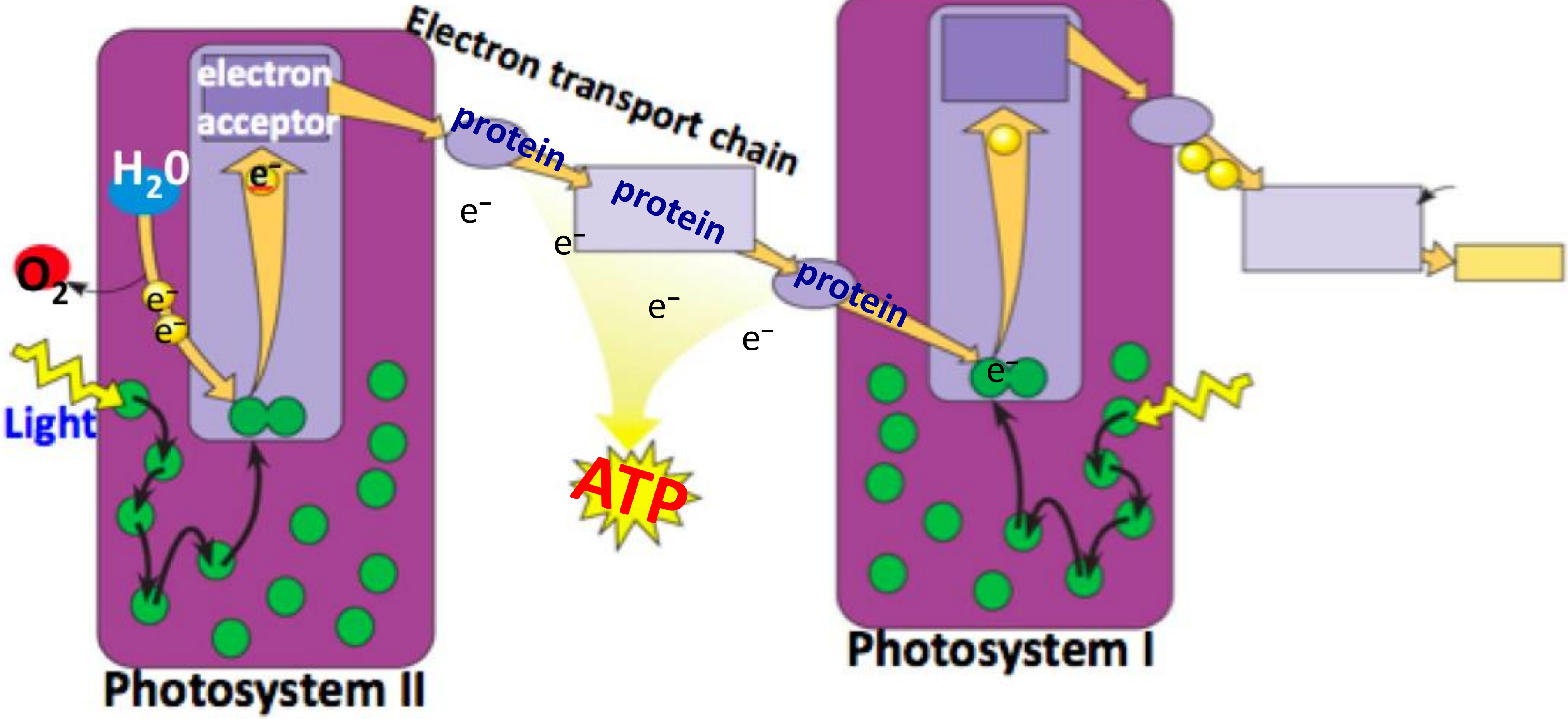
These electrons replace the high-energy electrons that chlorophyll has lost to the electron transport chain.



The <u>oxygen</u> is considered a waste product and is released into the <u>air</u>.

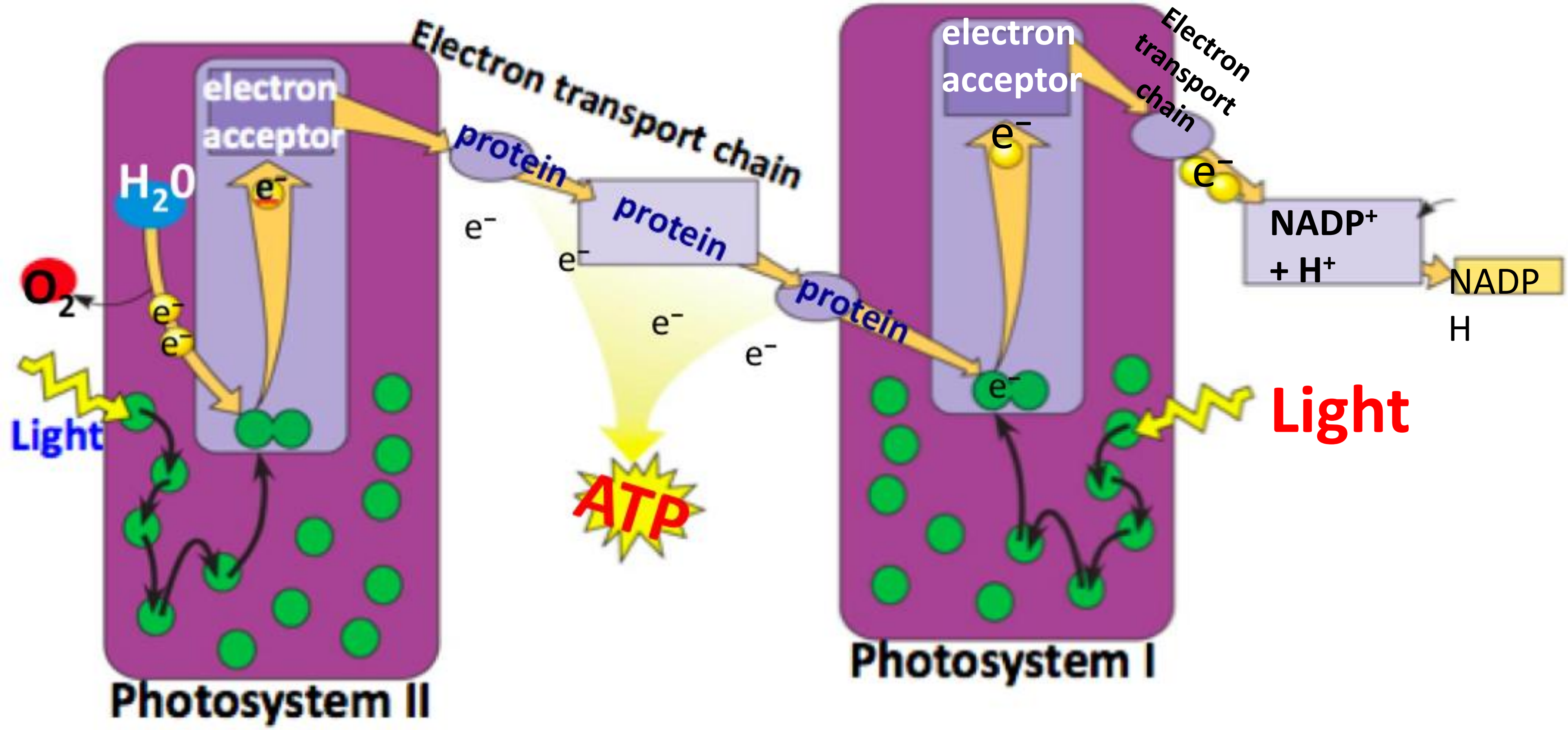
This splitting apart of water molecules is responsible for nearly all of the oxygen in our atmosphere.

The hydrogen ions from the water are released inside the thylakoid.



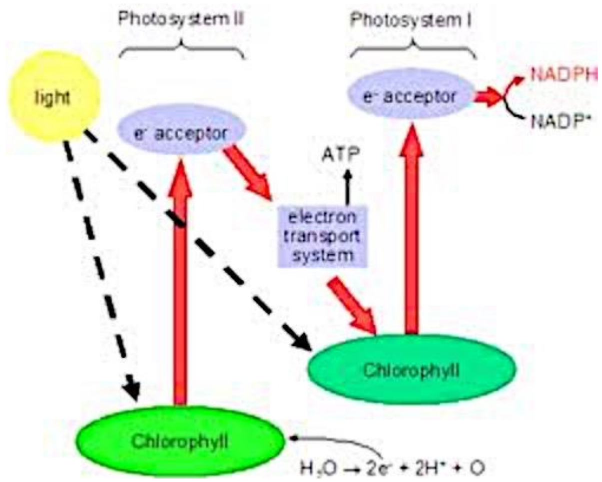
The high-energy electrons move through the electron transport chain from photosystem II to photosystem I.

As the electrons are passed down the electron transport chain, protein molecules use the energy from these electrons to create ATP.



The chlorophyll molecules in photosystem I absorb energy from the sun and use it to re-energize the electrons.

The electron carrier $NADP^+$ picks up these high-energy electrons, along with a H^+ to form NADPH.



This is a complicated process so let's not lose sight of the big picture:

The purpose of the light dependent reactions is to <u>produce ATP and NADPH that are needed for the light independent reactions</u>.

Water molecules are continuously _split__. The _hydrogen_ will accumulate inside the thylakoid. The _oxygen_ is released to the atmosphere.

This takes place along the _thylakoid_ membrane.

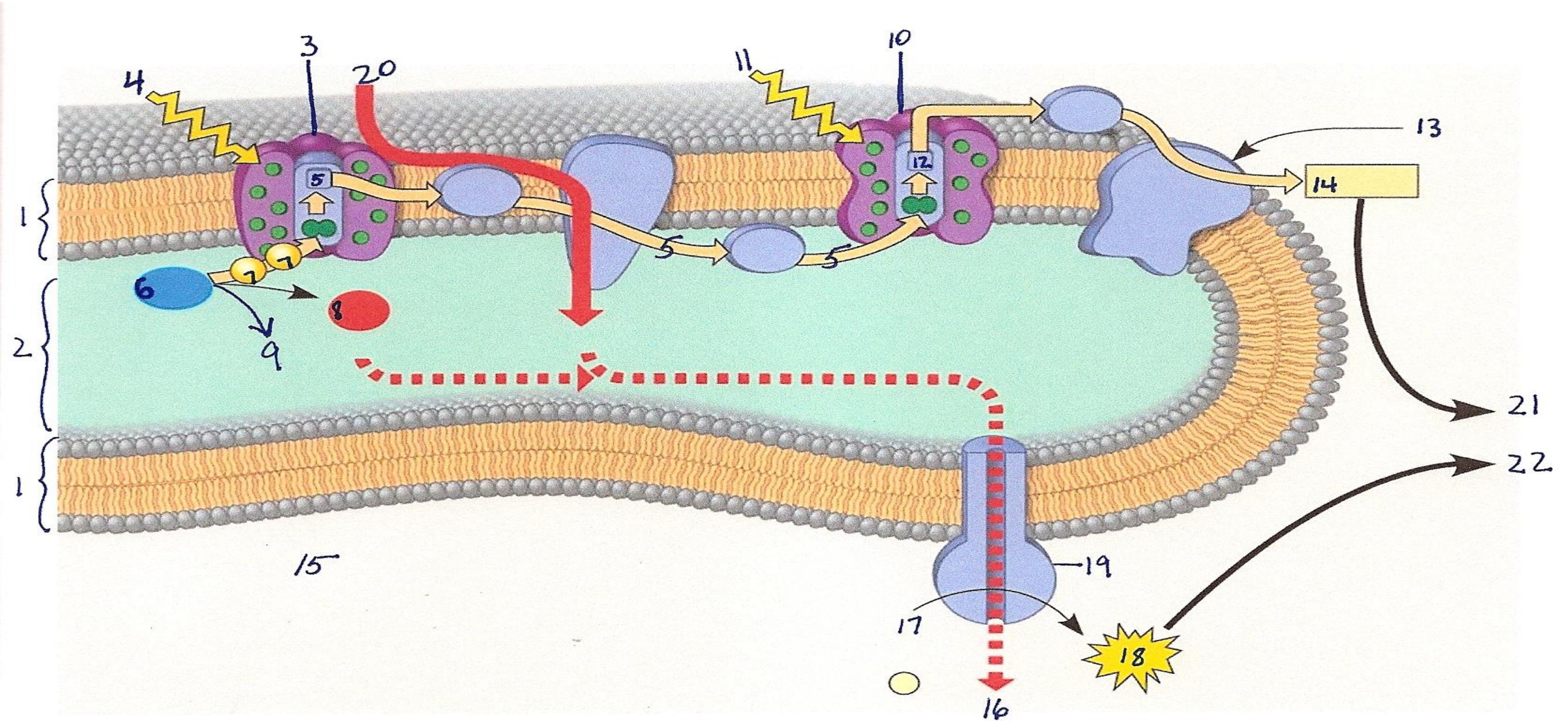
The light dependent reactions pass electrons continuously from water to NADPH.

The two photosystems work together using the <u>light energy</u> from the sun to produce <u>ATP and NADPH</u>.

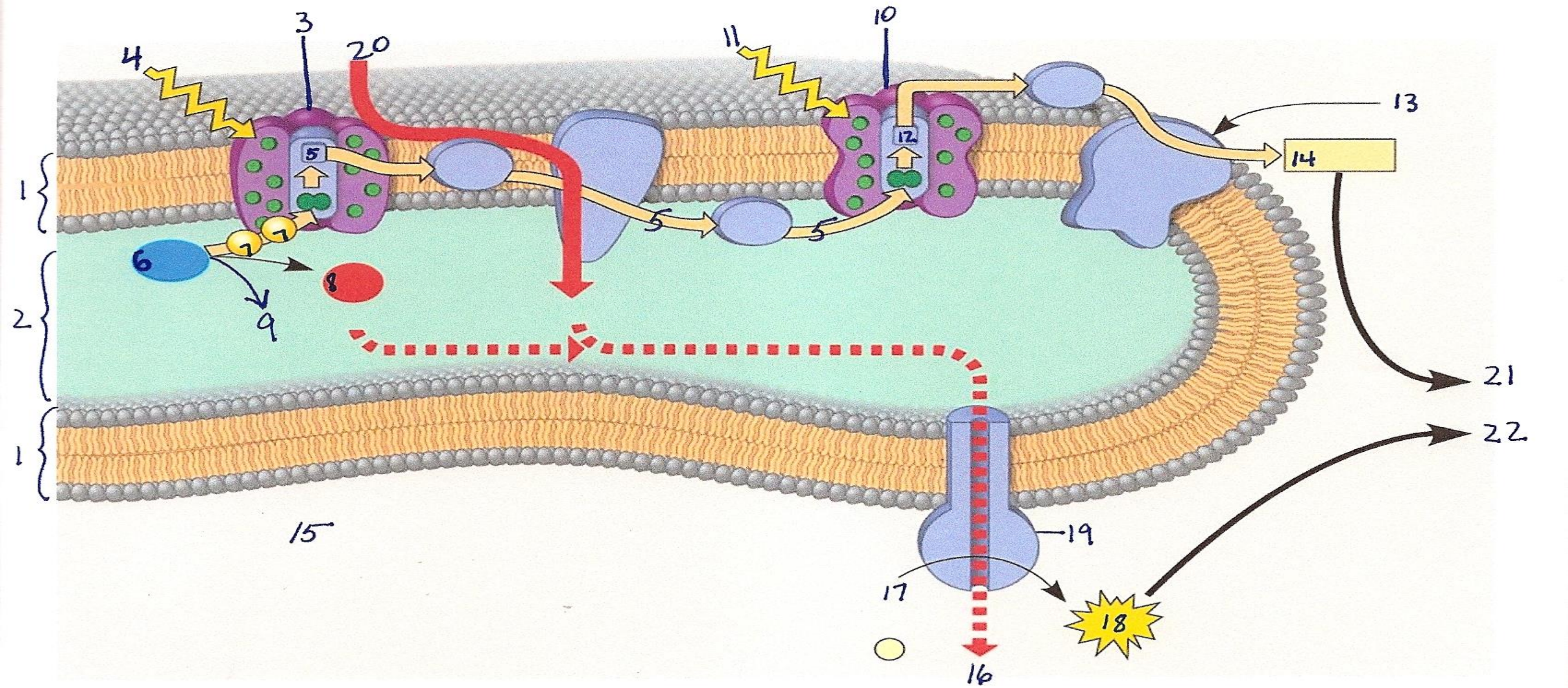
Um, is that an earworm?

- https://www.youtube.com/watch?v=yrQzEw9xY5k

The Light Dependent Reactions – The Light Reaction – A More Detailed View

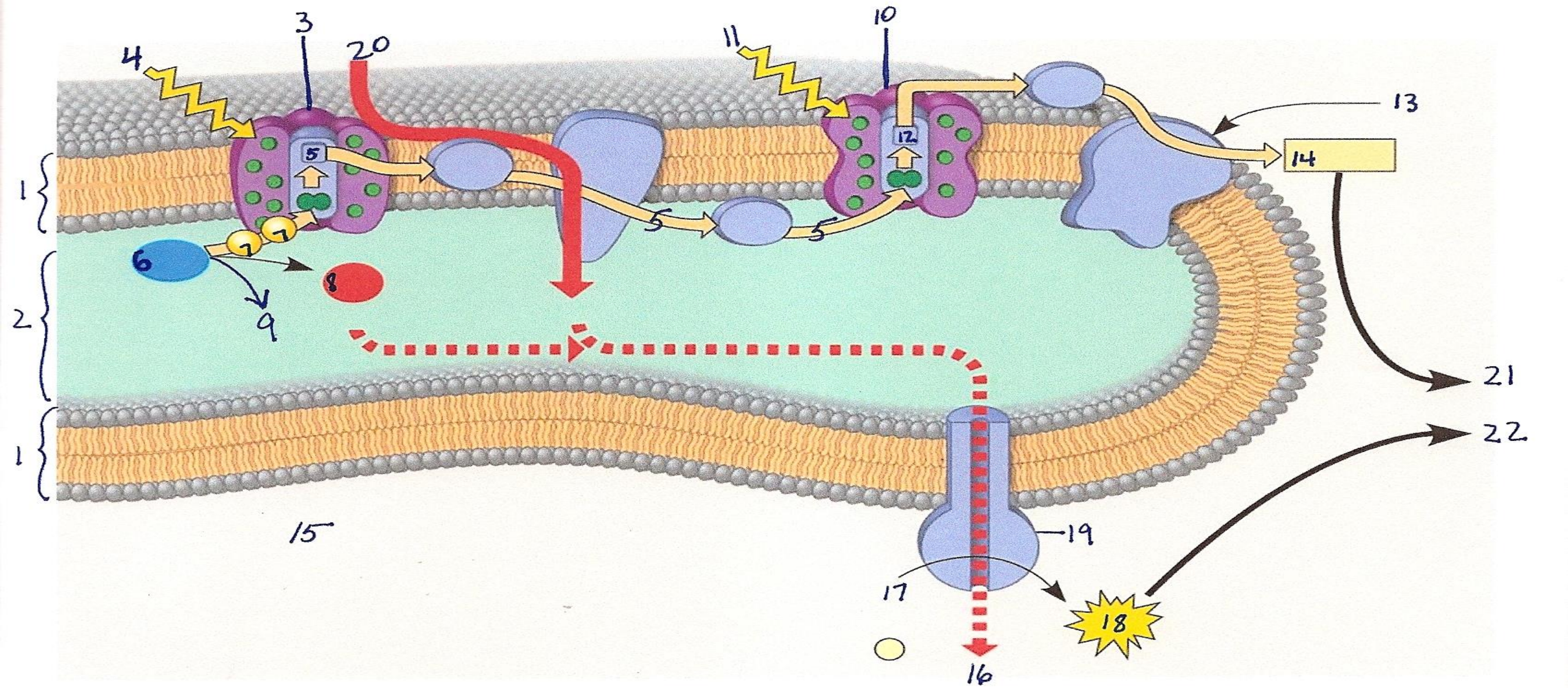


1. These are the membranes composing the _thylakoids_. Thylakoids are found inside the _chloroplasts_. Big stacks of thylakoids are called _grana_.



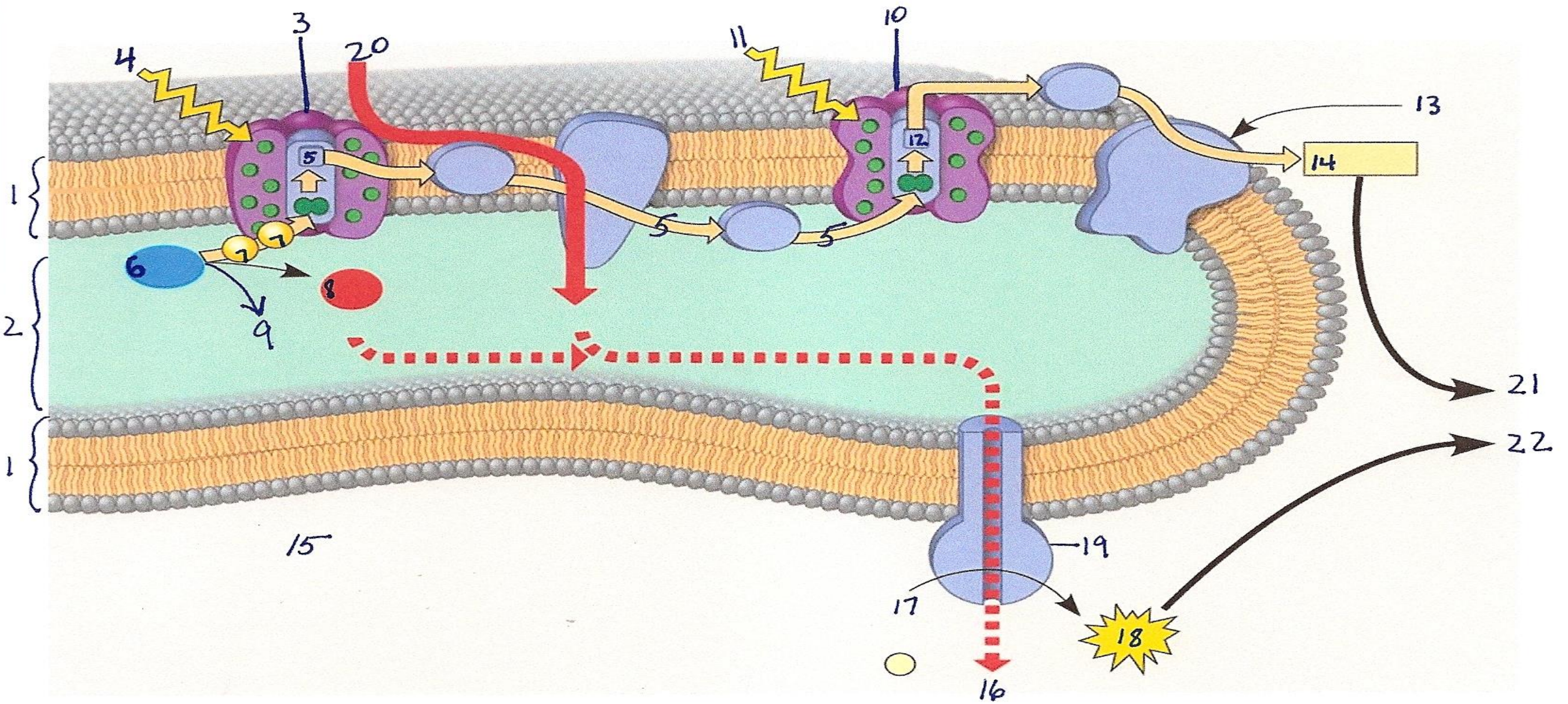
2. This is the middle of the thylakoid. It is called the thylakoid space.

3. Photosystem II: This is a collection of chlorophyll molecules that absorb the light energy from the sun.



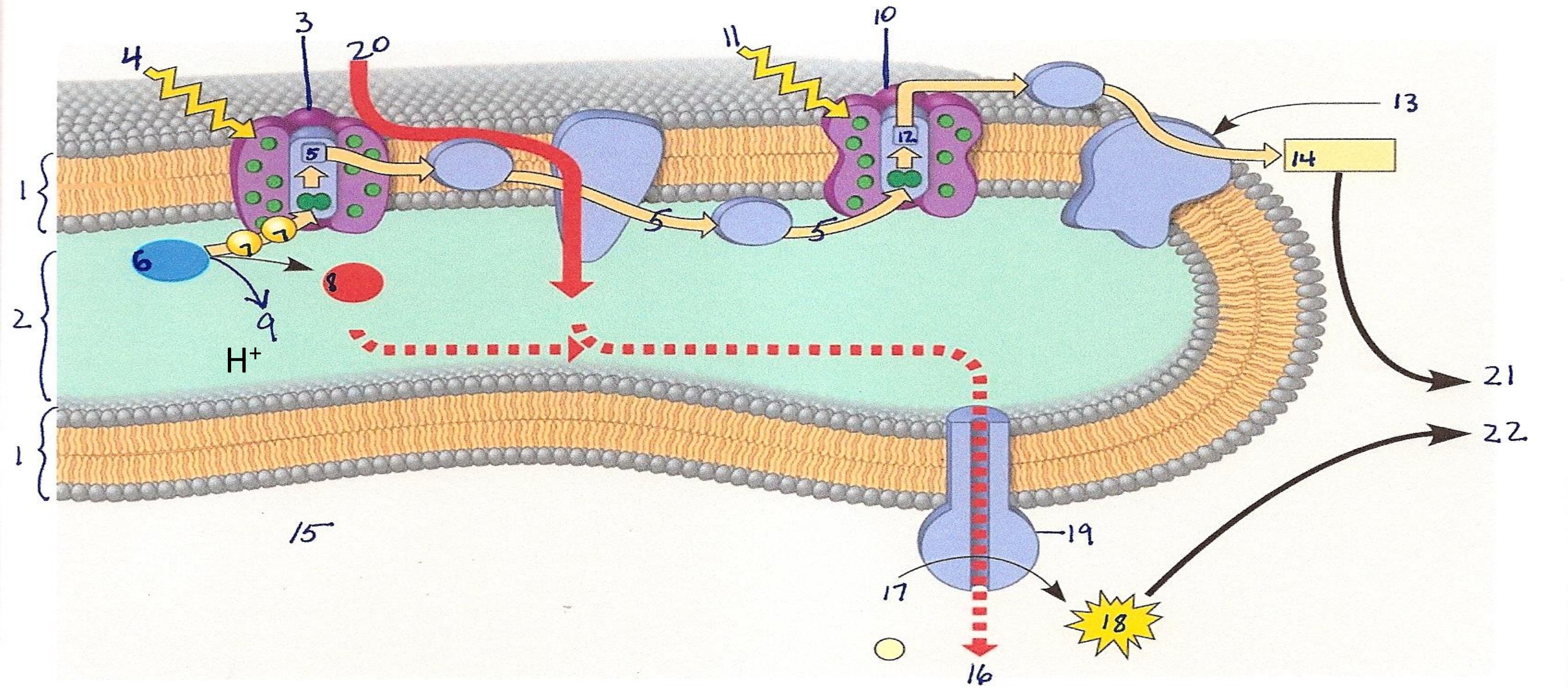
4. _Sunlight__ strikes the surface of the leaf. The chlorophyll molecules absorb the energy from the sun.

5. This light energy increases the _energy_ level of the _electrons__ in chlorophyll molecules. These high-energy electrons _are passed to the electron transport chain__.



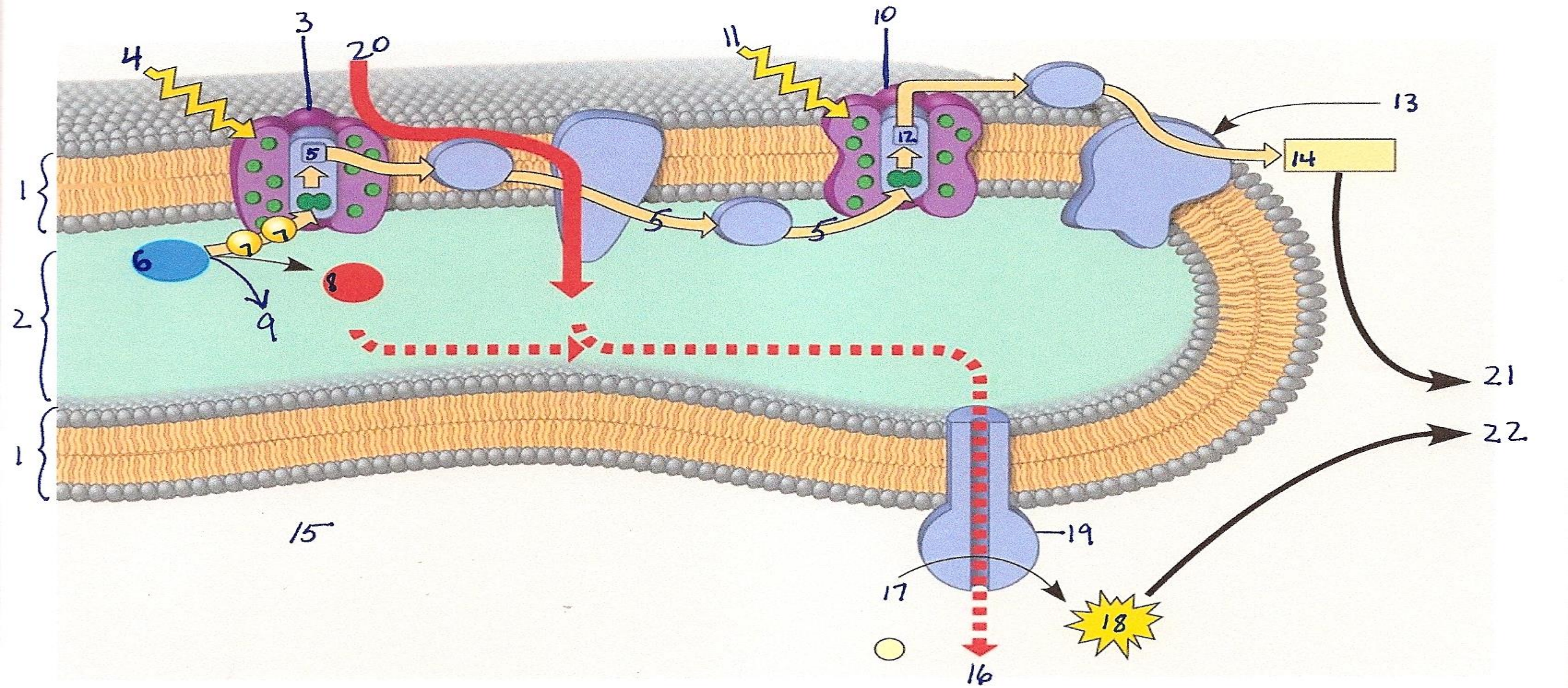
6. The electrons that were _lost_ must now be _replaced_. Enzymes in the thylakoid membrane break apart _water_ molecules into _2 electrons, 2 H^+ ions, and 1 oxygen atom_.

7. These electrons replace the high-energy electrons that chlorophyll has lost to the electron transport chain.

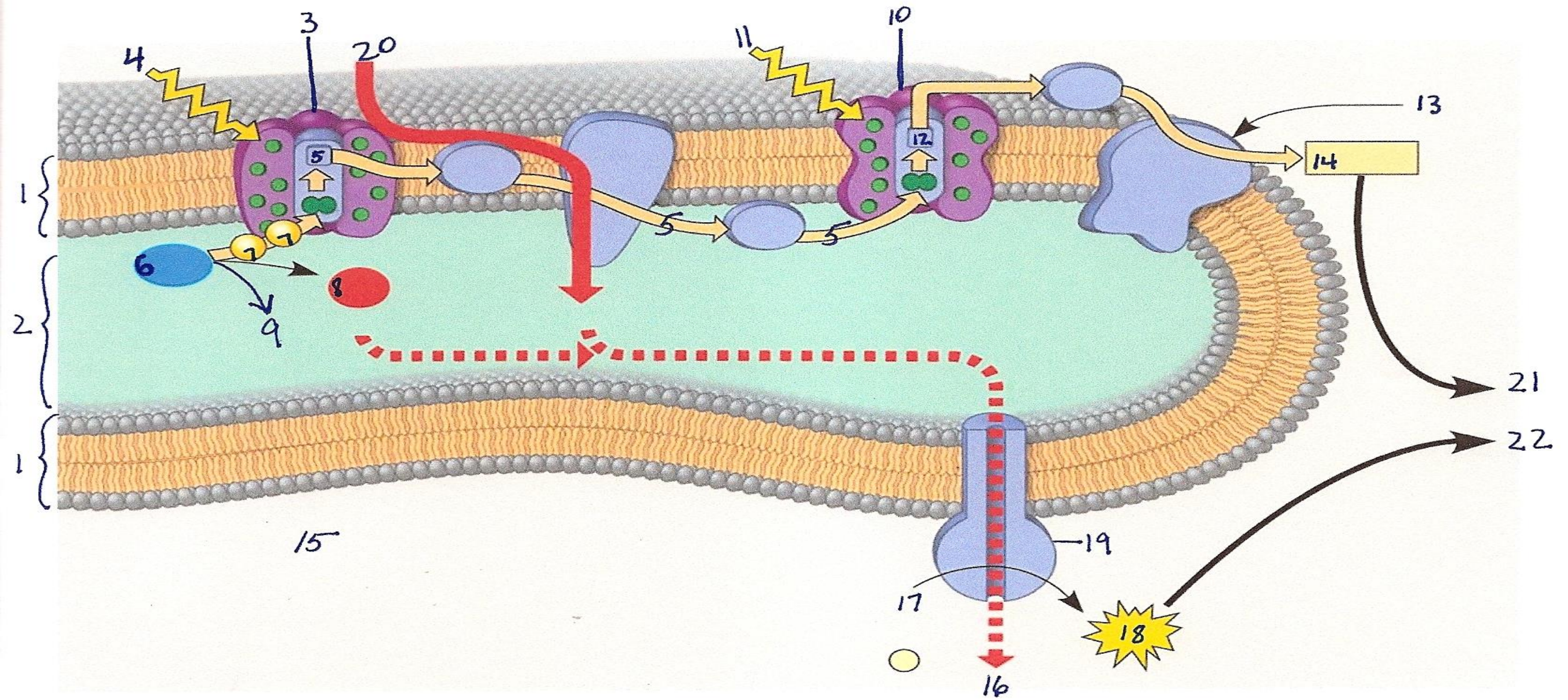


8. The oxygen is considered a waste product and is released into the air.

9. The hydrogen ions from the water are released inside the thylakoid.

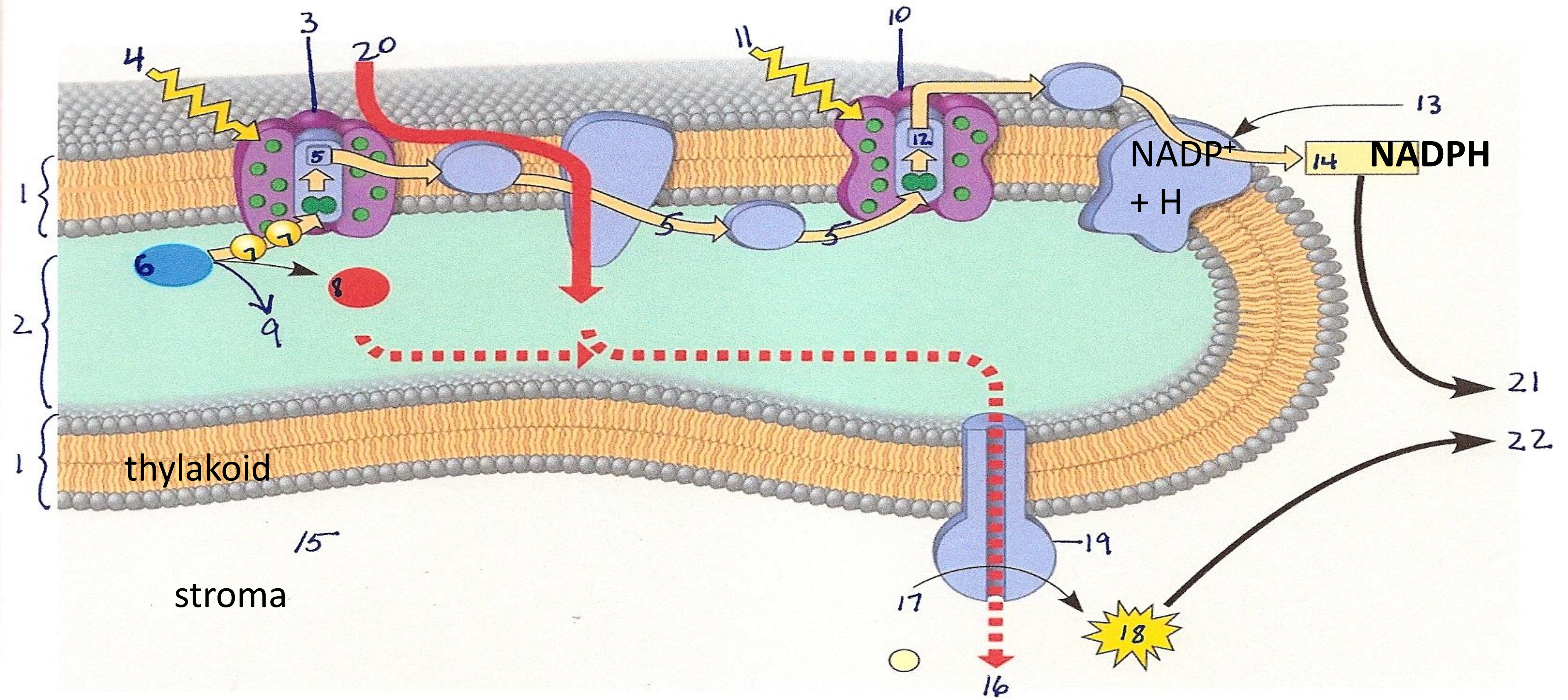


10. The high-energy electrons move through the electron transport chain from photosystem II to photosystem I. As the electrons are passed down the electron transport chain, protein molecules use the energy from these electrons to create ATP.



11. The chlorophyll molecules in photosystem I absorb energy from the sun and use it to re-energize the electrons.

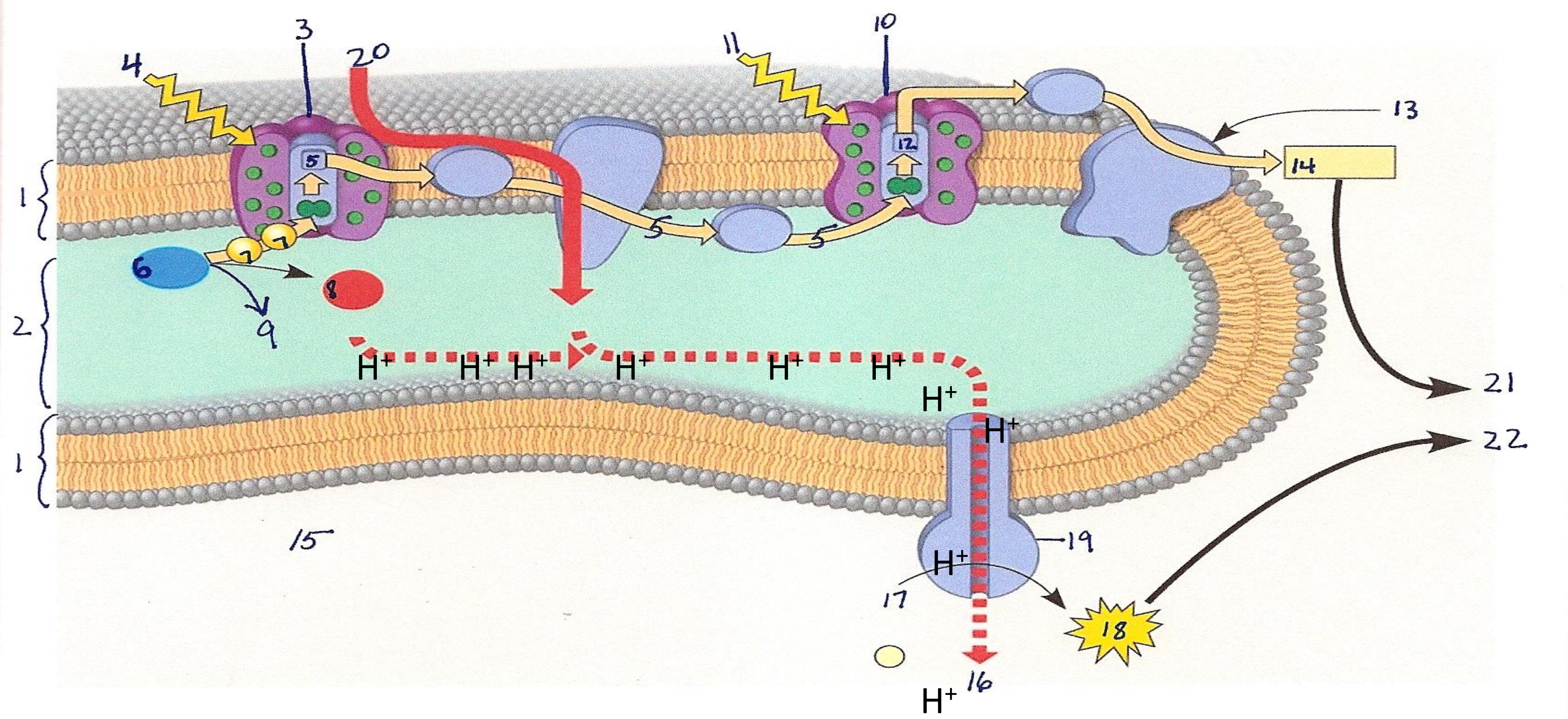
12. These electrons are passed down a second electron transport chain to the electron acceptor called $NADP^+$.



13. ______ NADP+ joins with one hydrogen atom and two electrons to form……

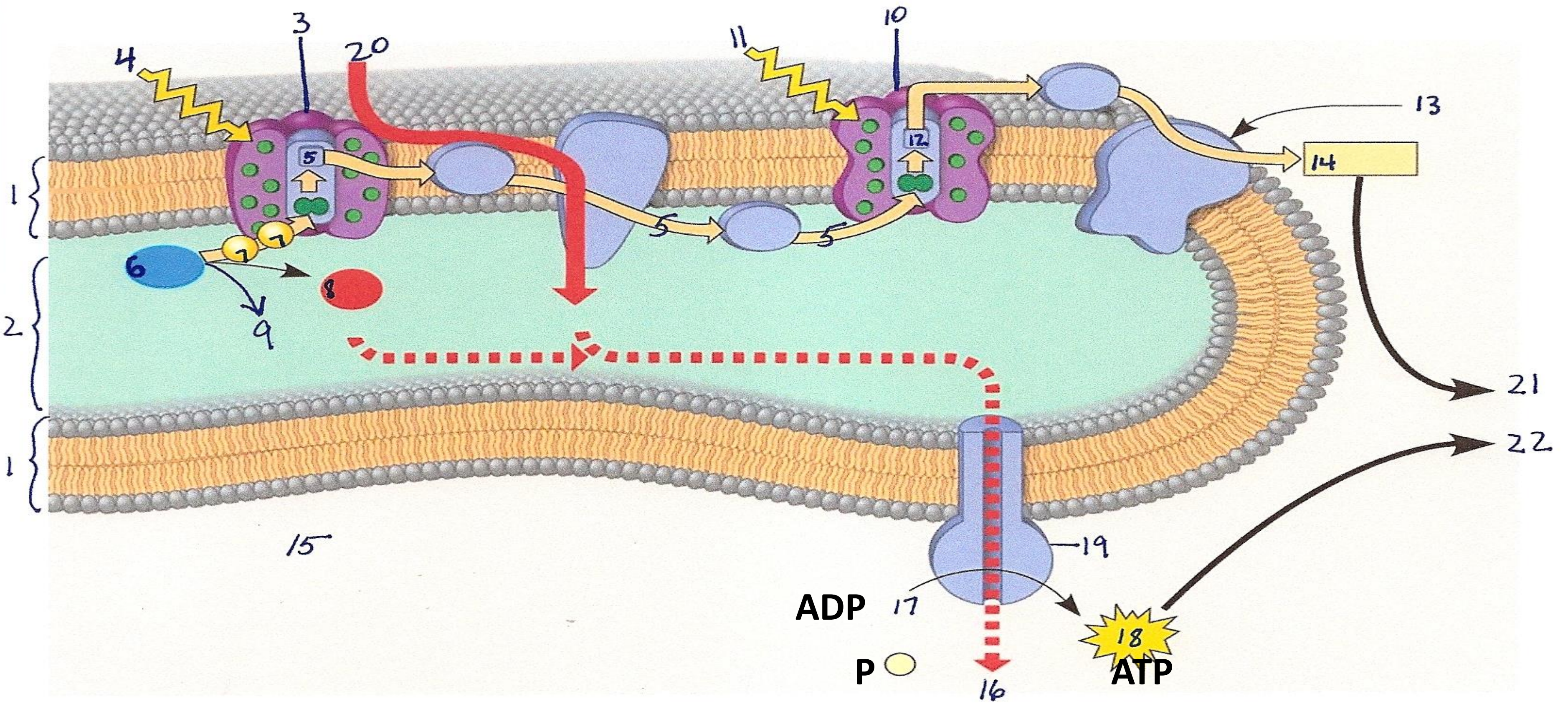
14. NADPH

15. This area of the chloroplast is called the _stroma_. It is a dense liquid area of the chloroplast.



16. _Hydrogen ions_ flow from an area of _high_ concentration inside the _thylakoid_ to an area of _low_ concentration in the _stroma_. The hydrogen is flowing through a protein enzyme called _ATP Synthase_. As the hydrogen flows through ATP synthase, the protein:

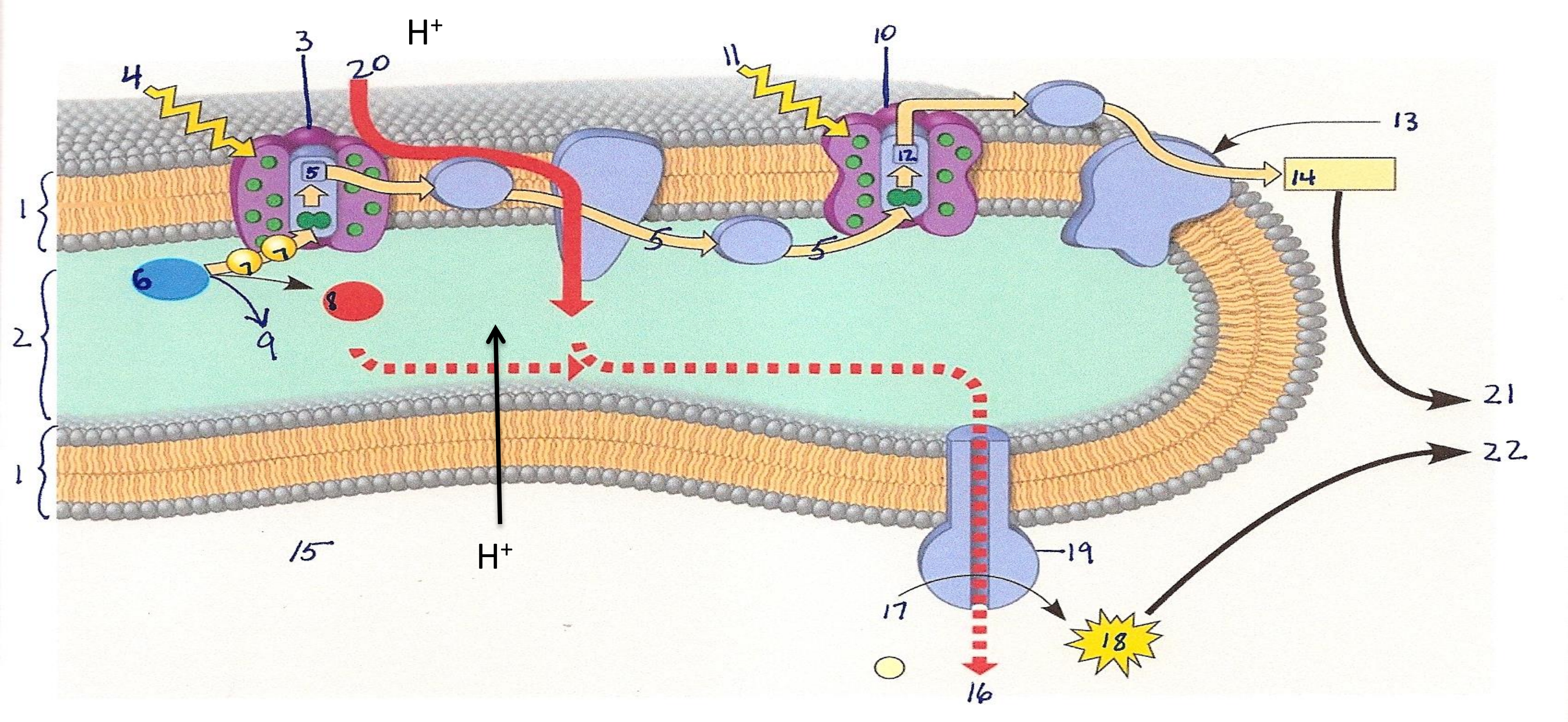
rotates just like a turbine being turned by water.



17. As this protein rotates, ATP synthase binds a _**phosphate**_ to _**ADP**_ to form ……

18. ATP.

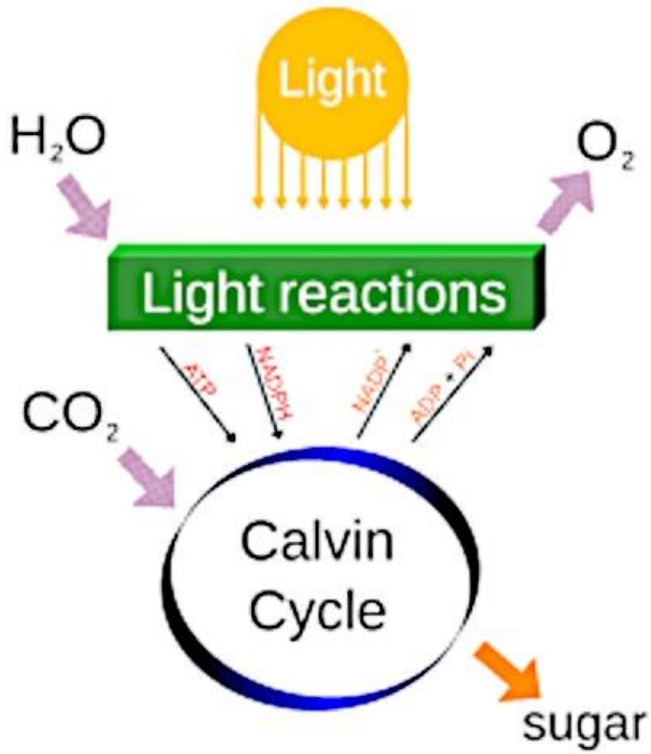
19. ATP synthase



20. Hydrogen ions are pumped back inside the _thylakoid space_ to keep the concentration of hydrogen very _high_ inside the thylakoid.

21. NADPH

22. ATP



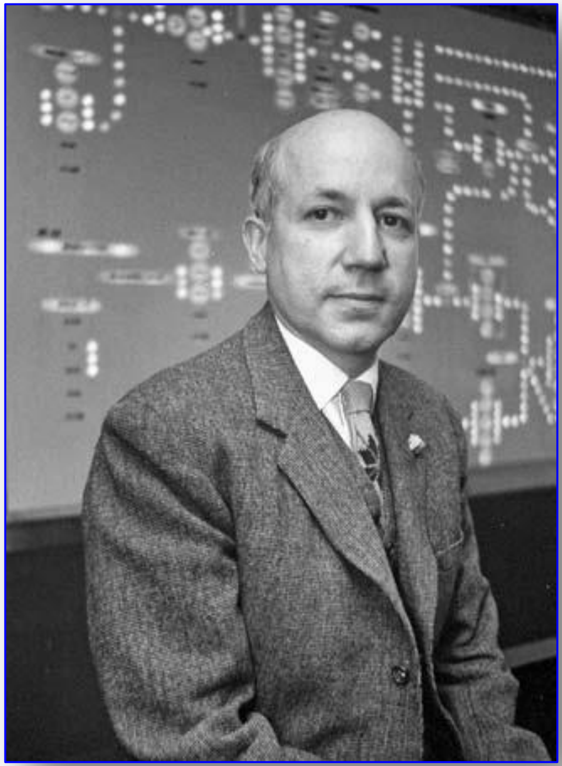
The purpose of the light reaction is to produce the high-energy compounds of ATP and NADPH which will be used in the light independent reactions.

And it appears to be… another earworm!

- https://www.youtube.com/watch?v=8-8YKLk-Nes

The Calvin Cycle

Melvin Calvin, Nobel Laureate of 1961

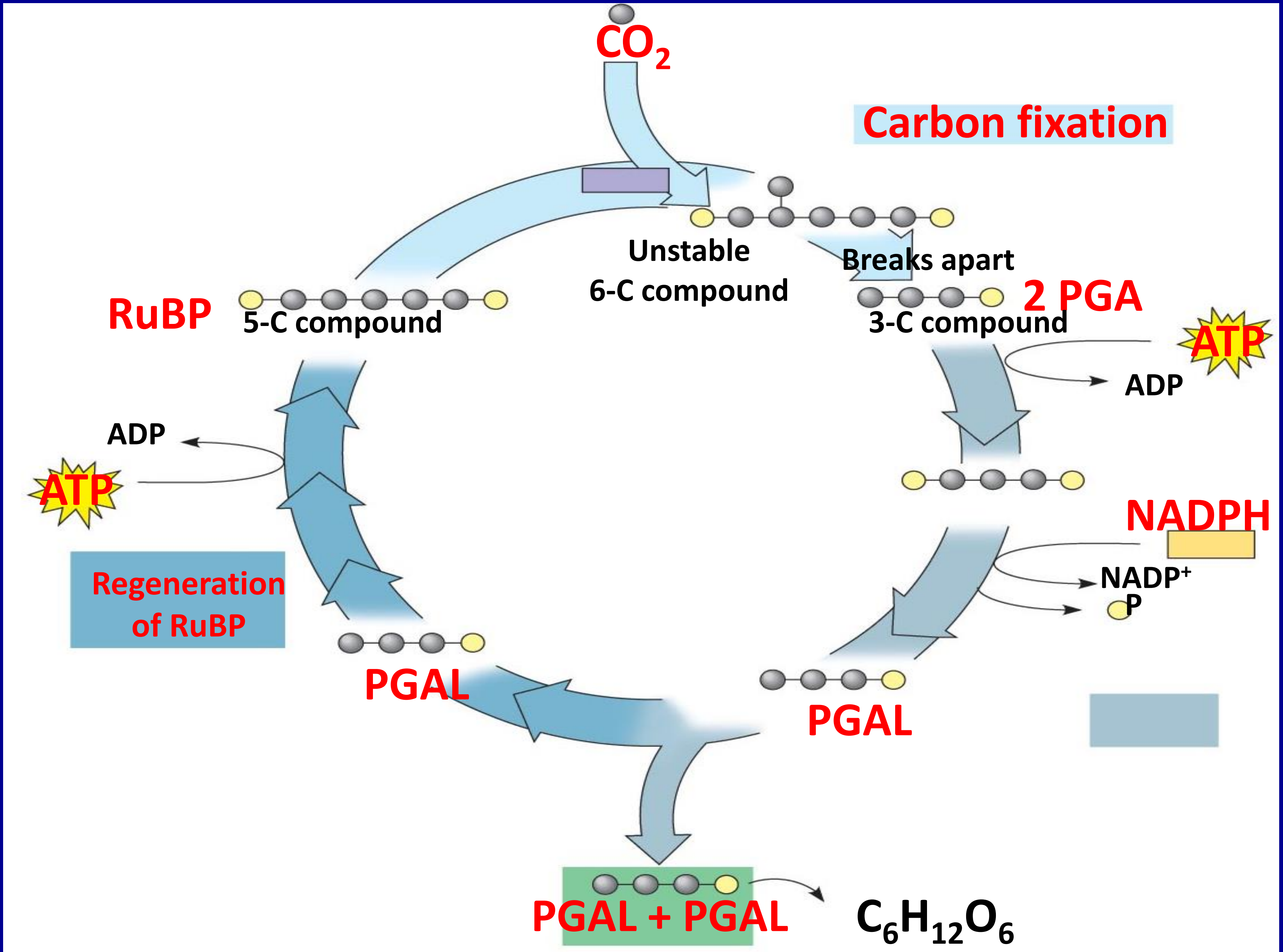


This set of reactions may be called by several names:

The Calvin Cycle, the Dark Reaction, or the Light Independent Reactions.

This occurs in the _stroma_ of the chloroplast.

The purpose of this stage is to take _carbon dioxide_ and the high-energy products from the light reaction (_NADPH and ATP_) and make _glucose_ molecules.


CO_2
Carbon fixation
Unstable
6-C compound
Breaks apart
2 PGA
3-C compound
ATP
ADP
RuBP
5-C compound
ADP
ATP
Regeneration
of RuBP
NADPH
$NADP^+$
P
PGAL
PGAL
PGAL + PGAL
$C_6H_{12}O_6$

Steps of the Calvin Cycle

1. Carbon dioxide is obtained from the atmosphere. It enters the leaf through the pores in the leaf called stomata.

2. The carbon from carbon dioxide is combined with a 5-carbon sugar called RuBP – Ribulose Biphosphate. This is referred to as carbon fixation.

3. This forms a very unstable 6-carbon compound that immediately breaks apart into 2 molecules of PGA, a three-carbon compound.

Steps of the Calvin Cycle

4. A series of reactions involving ATP and NADPH converts a molecule of PGA into PGAL. PGAL is also a three-carbon compound.

There are 2 possibilities for the PGAL:

① Two molecules of PGAL are combined together to form a molecule of glucose.

② Some of the PGAL is converted by a series of reactions into more RuBP so that the reaction can occur again.

The Water Loss Dilemma

The number one problem that land plants face is dehydration.

Plants must open their _stomata_ to let in the _carbon dioxide_ that is required for photosynthesis. But anytime the stomata are open, there will be excessive _water_ loss through the stomata.

There will have to be trade-offs or compromises between photosynthesis and the prevention of excessive water loss.

On a hot, dry day, most plants will close their stomata to conserve water. But with the stomata closed, photosynthesis will drastically slow down since no carbon dioxide can enter the leaf.

Factors Affecting the Rate of Photosynthesis

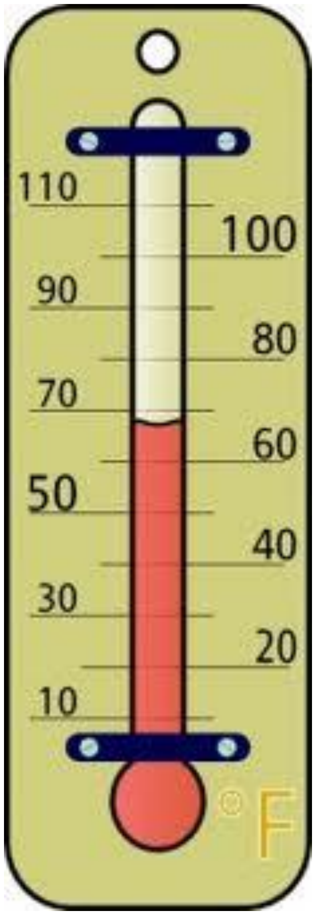
Water

Water is required in the light dependent reactions. Water is obtained from the ground by the roots.

A shortage of water in the ground can slow or stop photosynthesis.

In order to prevent water loss from the plant, plants are covered with a waxy cuticle.

Temperature



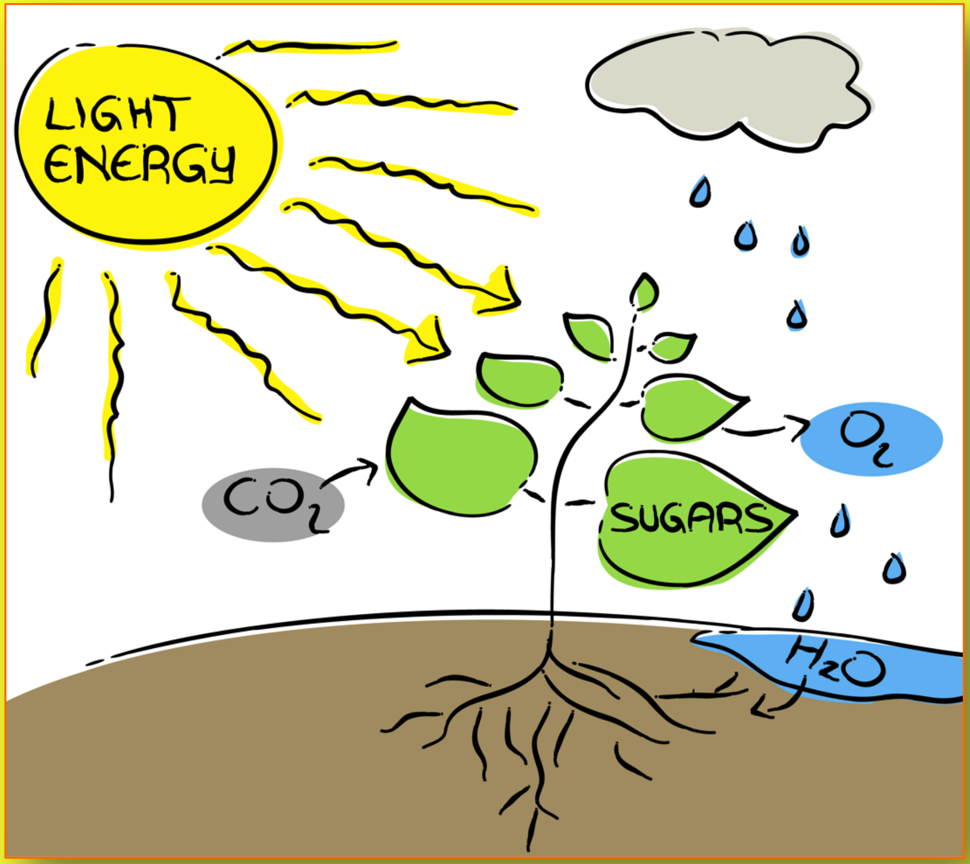
The process of photosynthesis depends upon the action of enzymes.

Enzymes work the best at temperatures between 0°C and 35°C.

Temperatures above or below this range may damage the enzymes and prevent them from functioning.

At very low or very high temperatures, photosynthesis may stop entirely.

Light Intensity



Increasing the light intensity increases the rate of photosynthesis.

To Sum It All Up:

The energy from the sun has been stored as chemical energy in glucose.