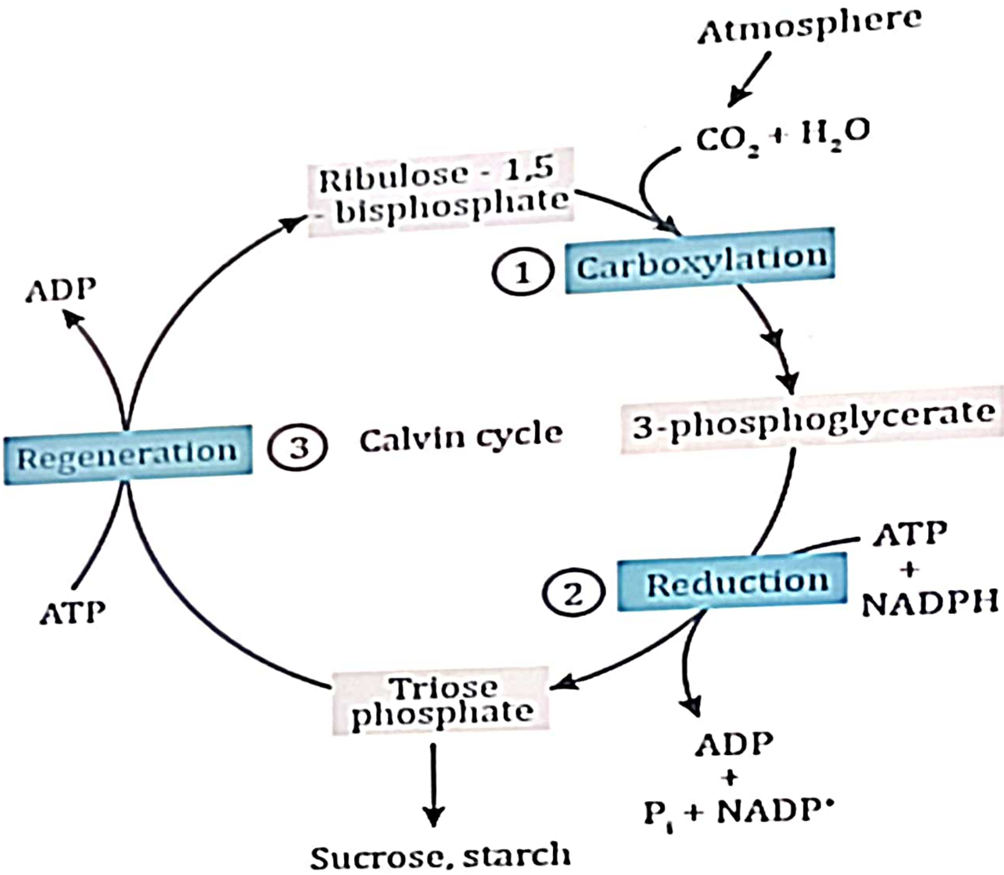
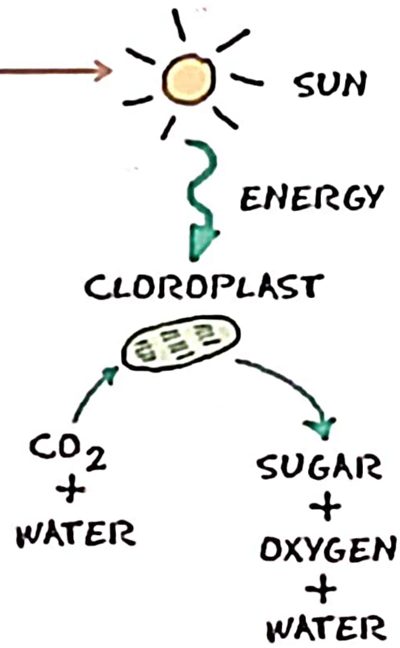
Calvin cycle

- The Calvin cycle reactions can be divided into three main stages:
- carbon fixation
- reduction
- regeneration of the starting molecule.



Photosynthesis is the process that converts solar energy into chemical energy that is used by biological systems (that means us).



Photosynthesis has 3 major events:

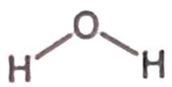
1. Sunlight is converted into chemical energy
2. Water (H_2O) is split into oxygen (O_2)
3. Carbon dioxide (CO_2) is fixed into sugars ($C_6H_{12}O_6$)

The photosynthesis reaction:

$6\ CO_2$	+	$12\ H_2O$	+	sunlight	→	$C_6H_{12}O_6$	+	$6\ H_2O$	+	$6\ O_2$
6 Carbon dioxide molecules		12 Water molecules				1 Sugar (glucose) molecule		6 Water molecules		6 Oxygen molecules

Each atom’s movement can be traced through the photosynthesis

A water molecule has 2 hydrogen and 1 oxygen atoms.



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

If 12 water molecules are used there are 24 hydrogen atoms (12 x 2 = 24) and 12 oxygen atoms total.

Before	After
6 carbon atoms 12 oxygen atoms	6 carbon atoms 12 hydrogen atoms 6 oxygen atoms
24 hydrogen atoms 12 oxygen atoms	12 hydrogen atoms 6 oxygen atoms
	12 oxygen atoms

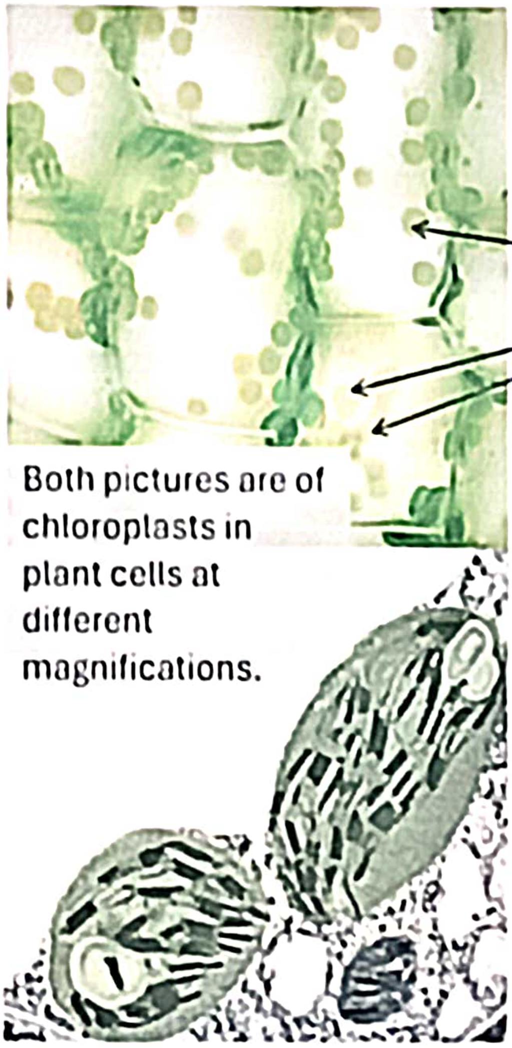
Each atom's movement can be traced

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

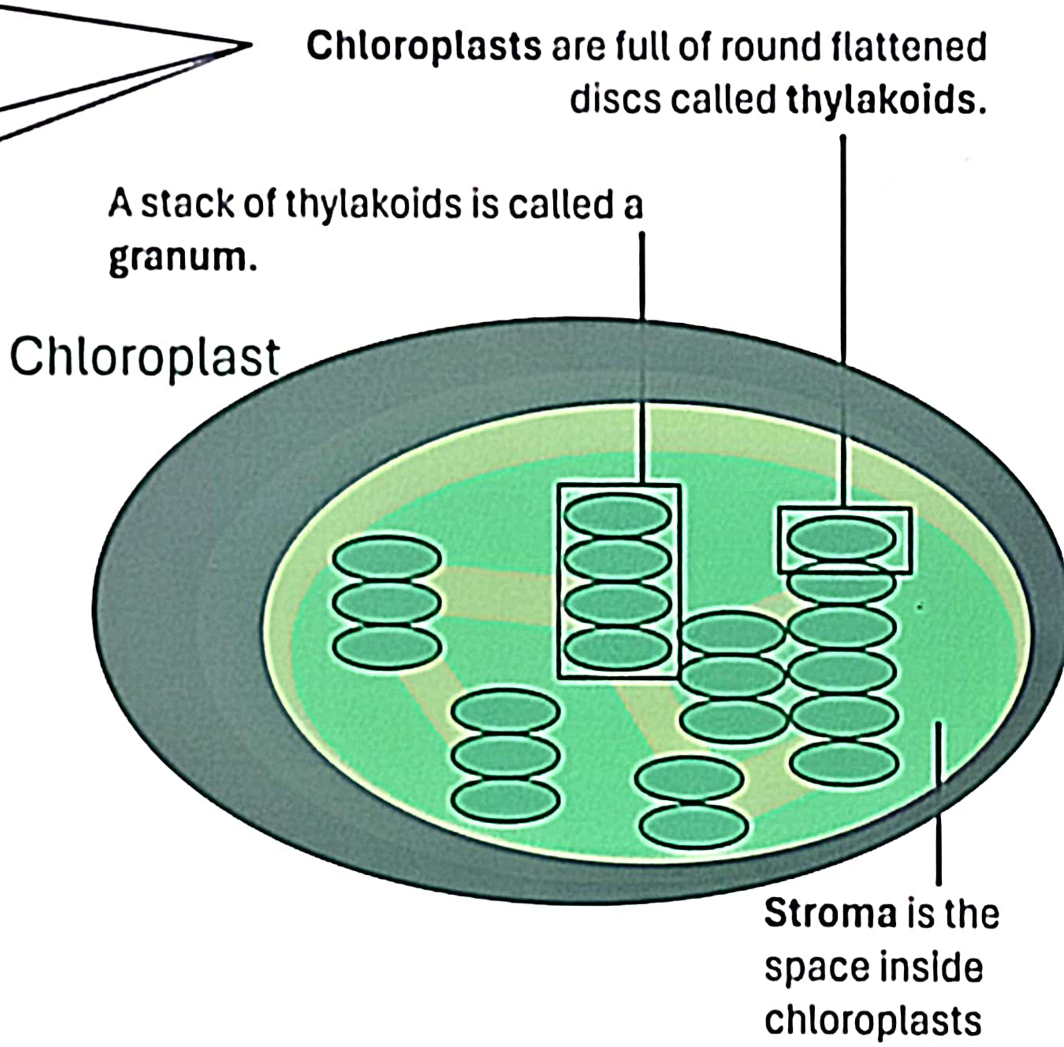
If you count every atom before and after the reaction they are balanced.

Before		After
6 carbon atoms 12 oxygen atoms 24 hydrogen atoms 12 oxygen atoms		6 carbon atoms 12 hydrogen atoms 6 oxygen atoms 12 hydrogen atoms 6 oxygen atoms 12 oxygen atoms
6 oxygen atoms 24 oxygen atoms 24 hydrogen atoms	=	6 oxygen atoms 24 oxygen atoms 24 hydrogen atoms

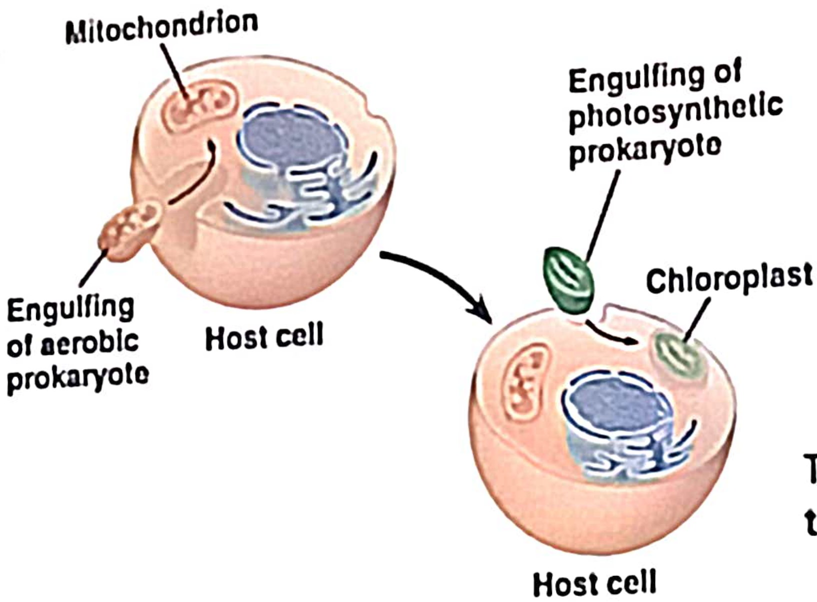
Through evolution, plant cells, certain bacteria and some algae have acquired chloroplasts to help carry out the photosynthetic reaction.
Chloroplasts are a plastid or plant cell organelle.



Both pictures are of chloroplasts in plant cells at different magnifications.



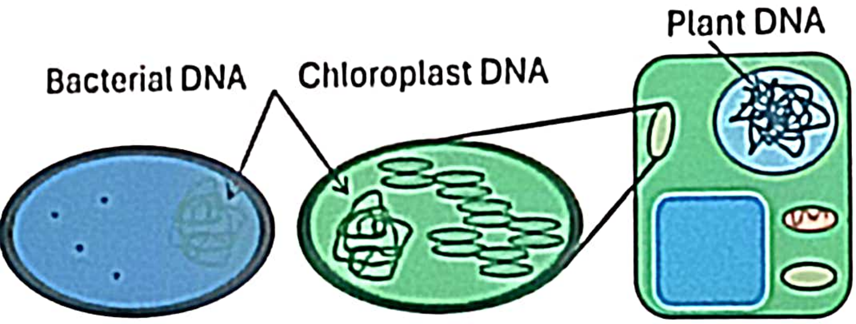
Where did chloroplasts come from?



A very long time ago, plant cells were once ancient eukaryotic cells that had enveloped a cyanobacteria. Eventually, the cyanobacteria became a part of the cell and dependent upon it for life which in turn gave the cell the ability to photosynthesize.

This is called the **endosymbiotic theory.**

(*endo* = inside)



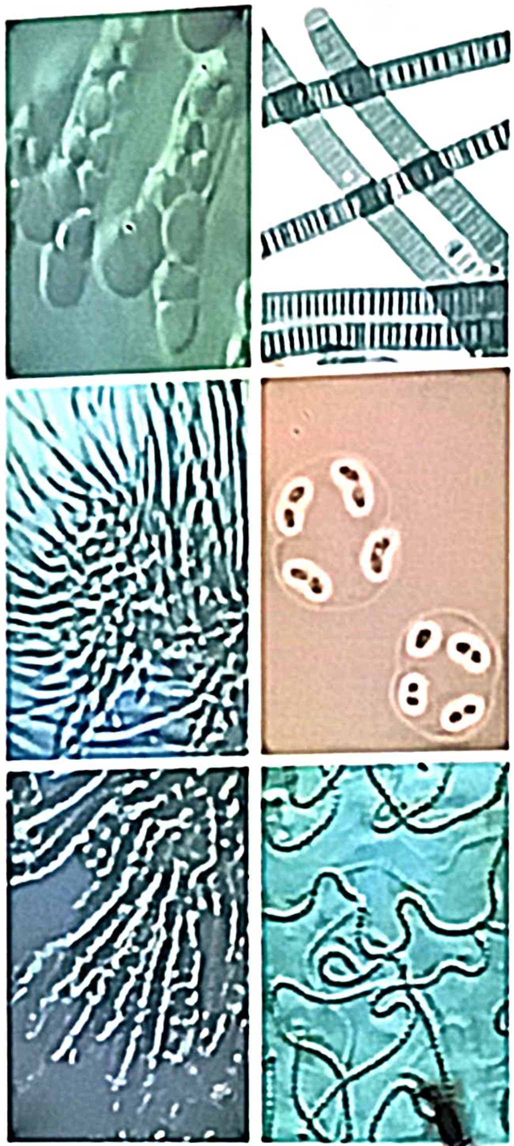
There are many reasons why scientists believe this theory. One is that chloroplasts have their own DNA that is different from plant DNA but similar to bacterial DNA.

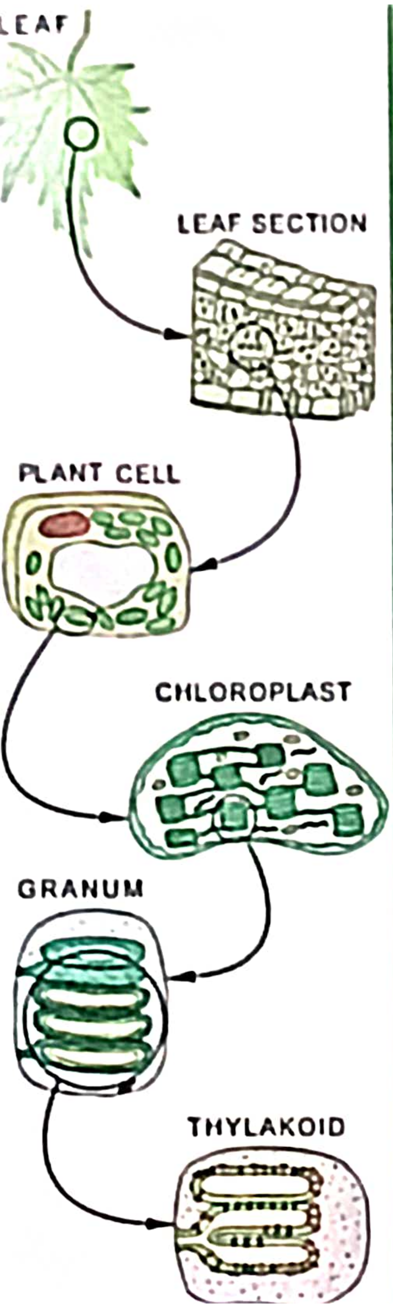
Cyanobacteria Today

Cyan comes from the Greek word *cyanin* which means aqua colored.

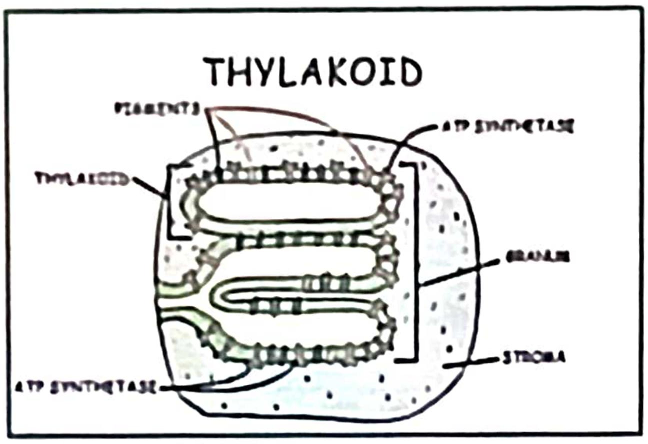
Not all bacteria that undergo photosynthesis are cyanobacteria, but all cyanobacteria are photosynthetic bacteria e.g. purple bacteria are not cyanobacteria but were the first bacteria discovered that can photosynthesize.

Cyanobacteria undergo photosynthesis in lakes, ponds, and oceans.





Photosynthesis in plants happens in the chloroplasts. Chloroplasts are full of **thylakoids** stacked in **granum.**

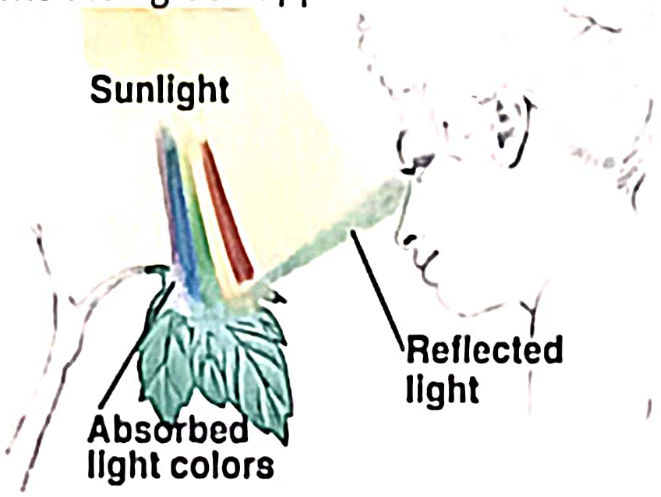


The thylakoid membranes are lined by pigments such as chlorophyll and cartenoids.

Chlorophyll is a green pigment and is the most abundant.

These pigments harvest light energy packets or **photons** when they absorb sunlight.

Chlorophyll absorbs all wavelength colors except green, which is reflected off giving plants their green appearance.



The Photosynthesis Reaction is divided into two parts:

Light Reactions

Light reactions or "light dependent reactions" capture light energy to power photosynthesis.
Light reactions occur during the day time.

They take place in the **thylakoids**.

Pigments in the thylakoid membranes form protein complexes called **Photosystem I** and **Photosystem II.**

These photosystems harvest photons to charge up energy carrying molecules that will power the dark reactions.

Dark

Dark reactions or "light independent reactions" do not need light energy to power their reactions and can occur day or night.

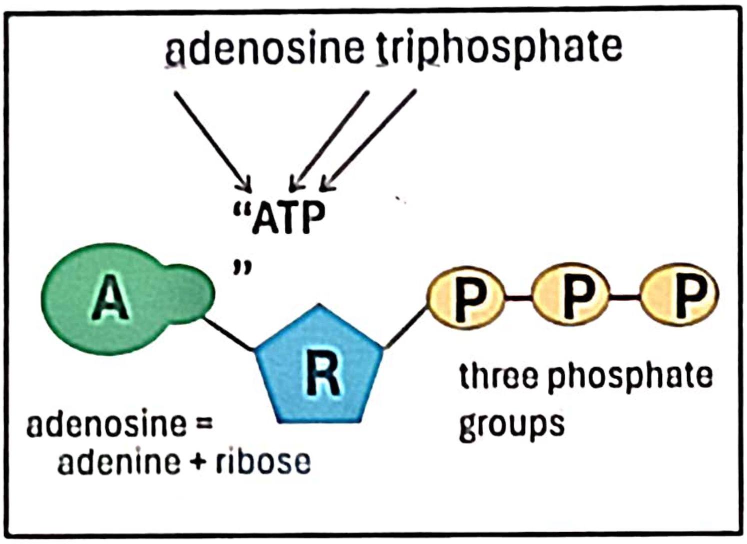
Discovered by three scientists, the dark reactions are also called the Calvin-Bensen-Bassham cycle or just **Calvin Cycle.**

Dark reactions occur in the **stroma** of chloroplasts (the space that surrounds thylakoids) and fix carbon dioxide into glucose.

Energy Carrying Molecules: ATP & NADP+

Both are energy carrier molecules used in photosynthesis and cellular respiration.

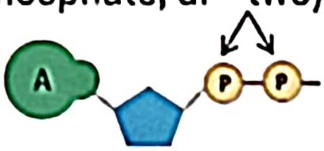
NADP+ can hold excited electrons (e^-) charged from the light energy harvested by chlorophyll to become NADPH. Eventually, NADPH passes the electron it's holding to power the dark reactions and reverts back to NADP+.

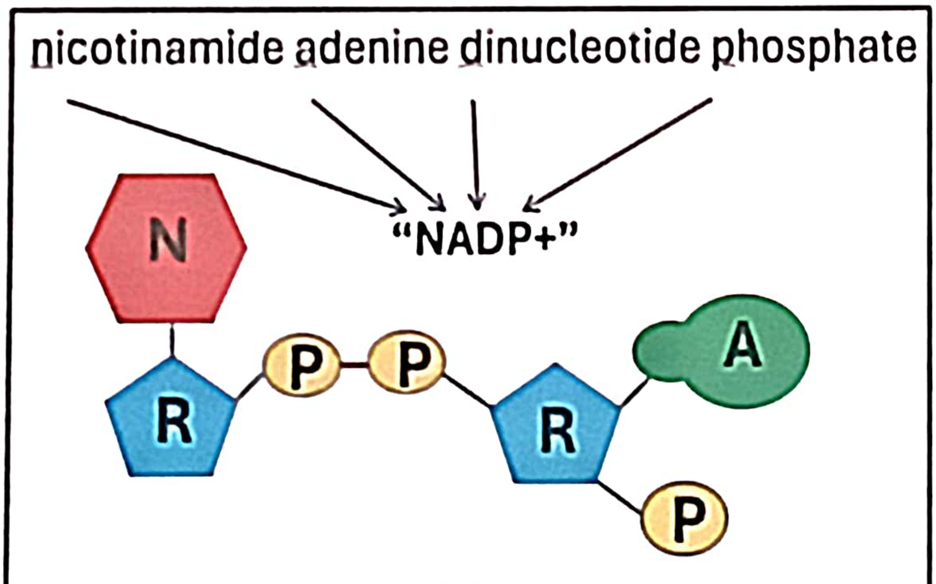


ATP is called the "cellular currency" because it is used to power all the reactions that take place in the cells of all living things.

When ATP's third phosphate is broken off it releases energy that the cell can use.

ATP is made when a third phosphate group is added to ADP (diphosphate, di = two).

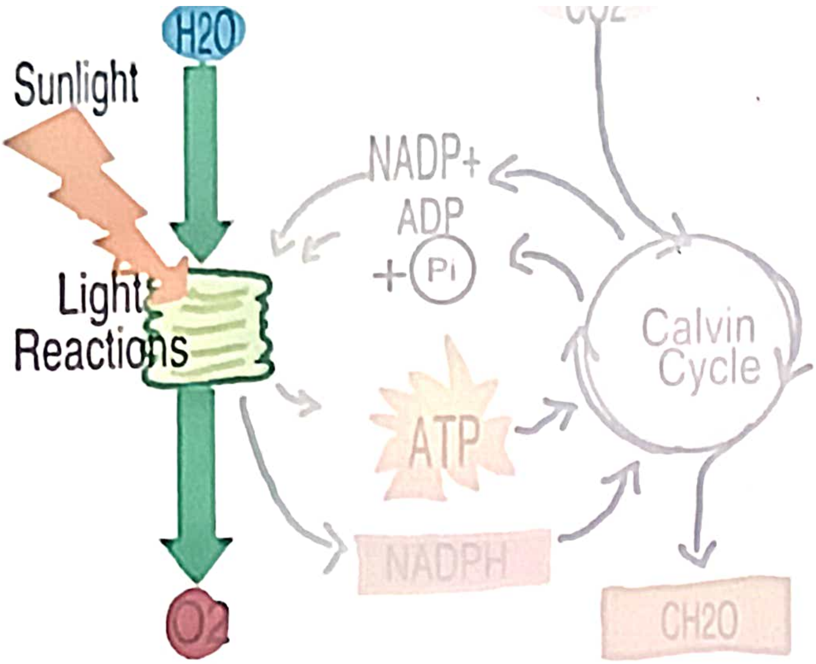




NADP is a very complex molecule, this is a simplification.

Light Reactions

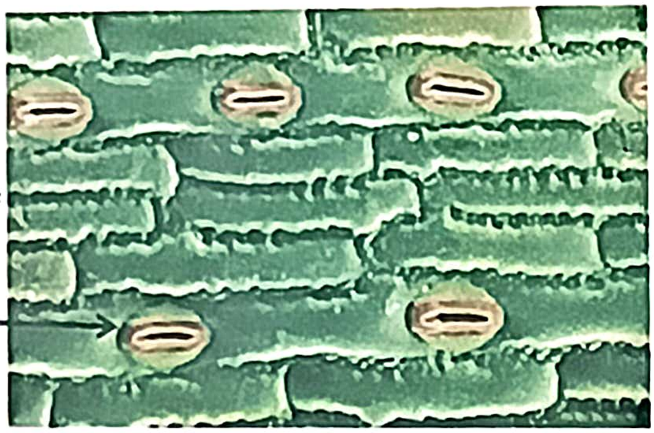
The energy absorbed by the chlorophyll during the light reactions is used to power **photosystem II** that breaks the bonds of water absorbed through the plant's roots.



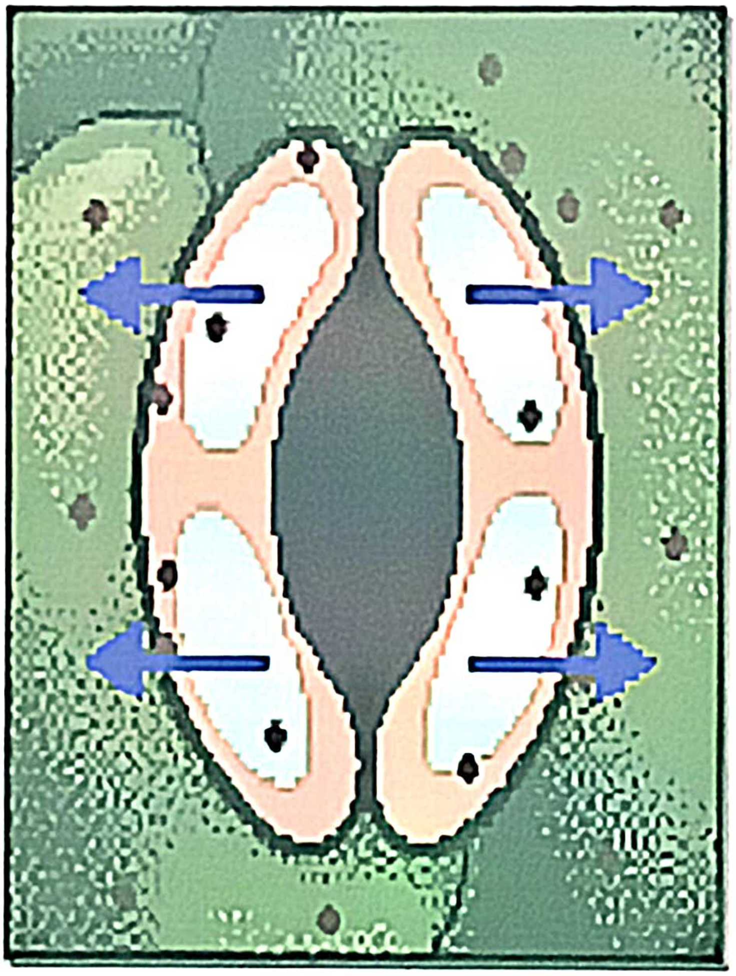
Freed oxygen atoms bind with each other to form the gas O_2.

O_2 is a byproduct of photosynthesis not used by the plant so it is released through the stomata of plants.

Stomata (Greek for *mouth*) are little pores in leaves that open and close to let oxygen out and carbon dioxide in.

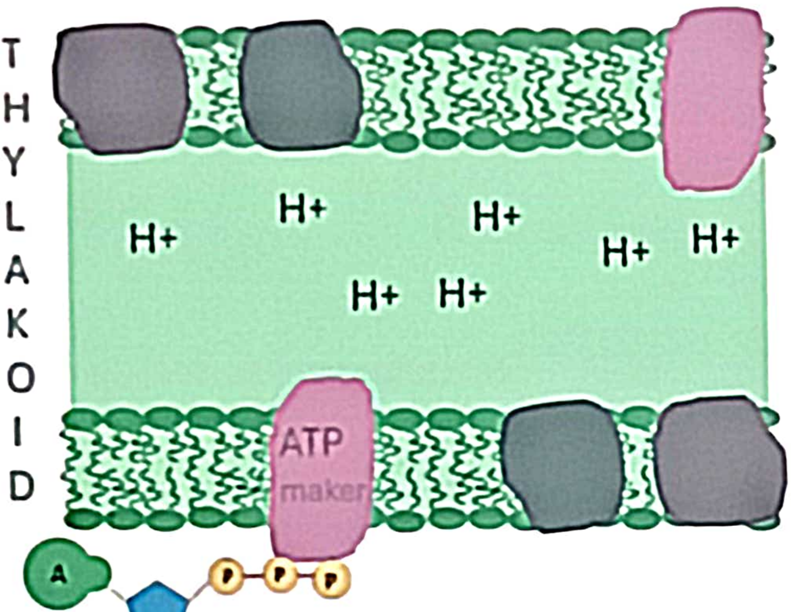


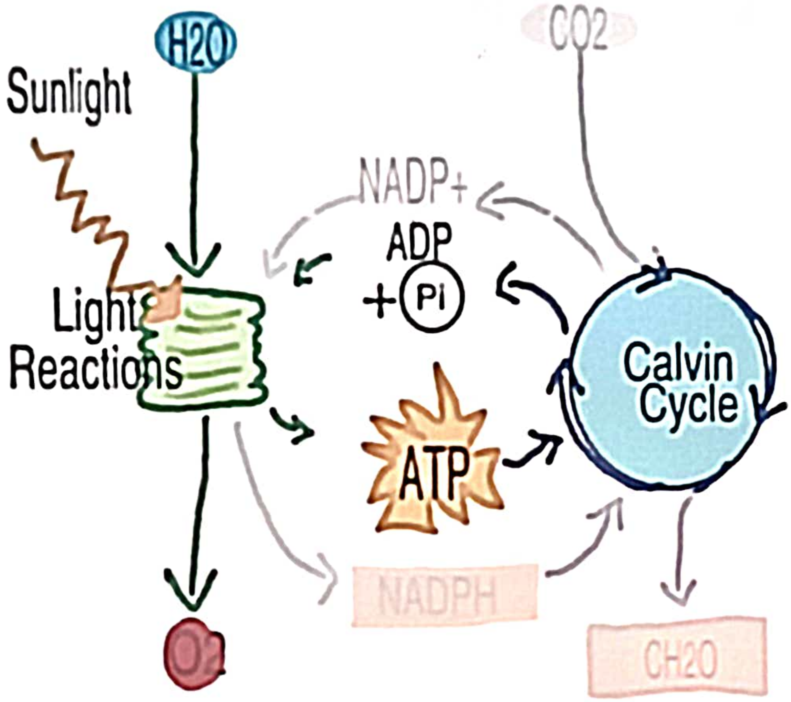
Opening and closing of stomata



Light Reactions

When water molecules break apart, the remaining two hydrogen atoms have a positive charge and are called **protons.** These protons are kept inside the thylakoid by the thylakoid membrane.





When there are more protons inside the thylakoid than in the stroma outside, protons want to leave the crowded thylakoid.

When the protons (H+) cross the membrane to leave, a protein uses their passage to power ATP production.

The protein **ATP synthase** attaches a phosphate group to ADP (D = *di* or two) making it ATP (T = *tri* or three).

Light Reactions Summary

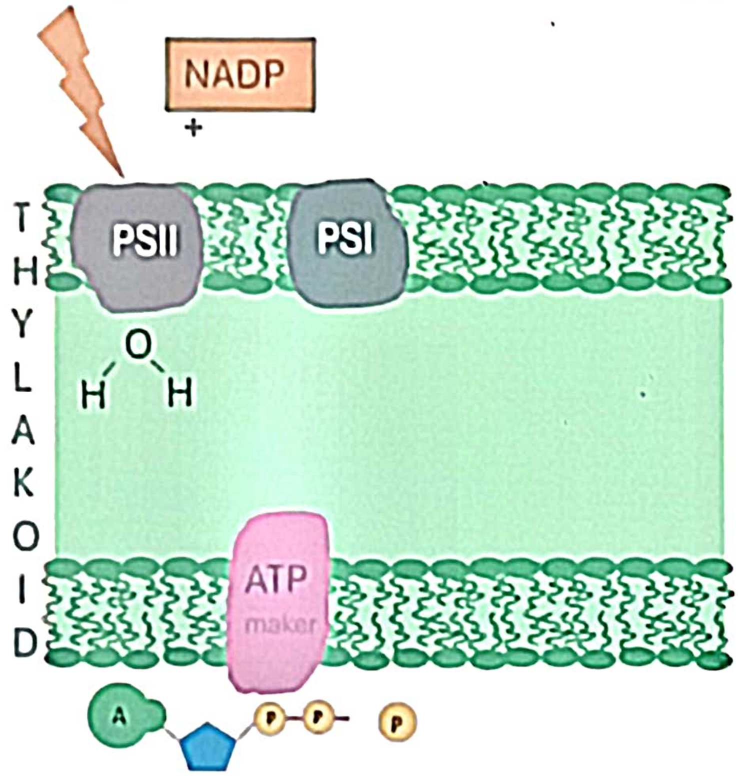
Photons are absorbed by the pigments to power photosystem I and photosystem II.

Photosystem II splits water molecules into two protons (H+) and oxygen atoms are expelled as O_2 gas through the stomata.

Protons cross the thylakoid membrane and power protein complex **ATP synthase to** make ATP.

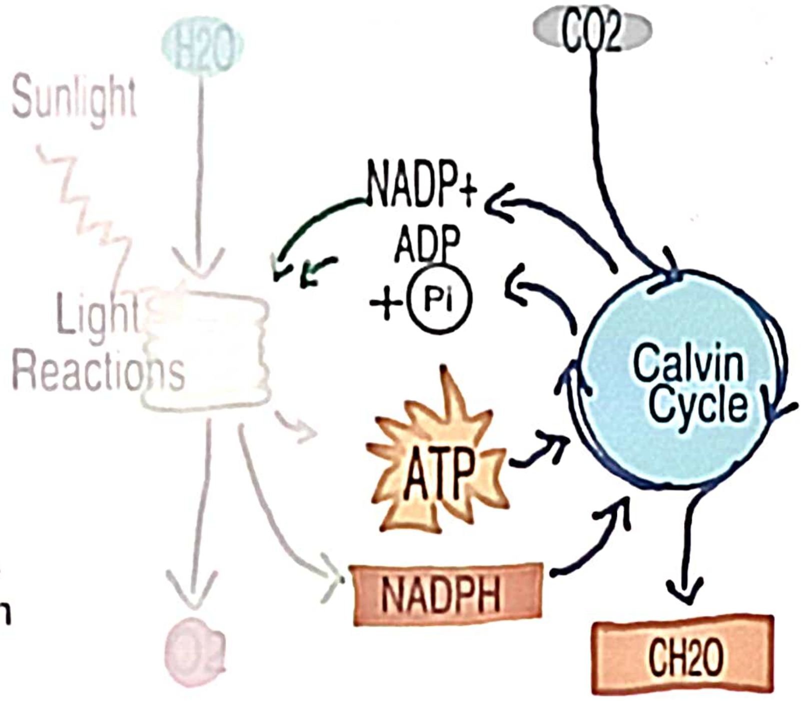
NADP+ is powered up by **photosystem I** to make NADPH to be used in the dark reactions.

Light dependent reactions finish with charged NADPH, ATP, and released O_2.

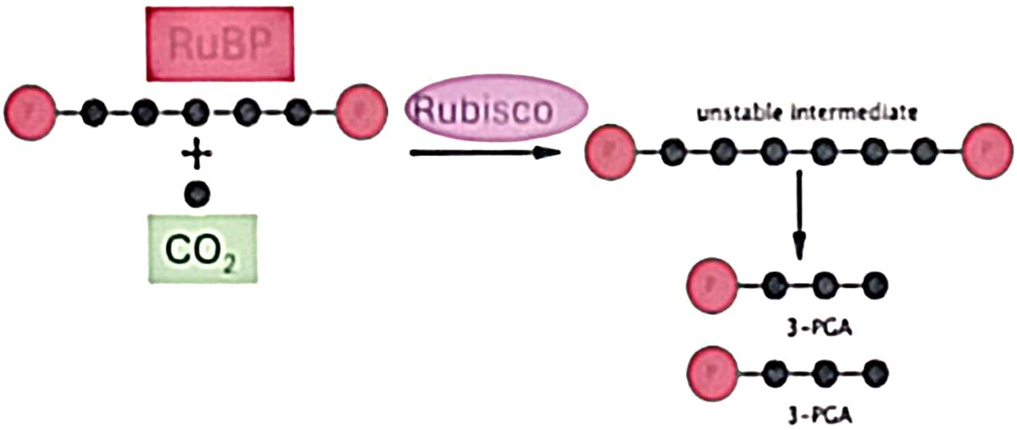


Dark Reaction

Also called the Calvin Cycle, the dark reactions start and end with the same products hence "cycle".
All the dark reactions take place in the **stroma of the chloroplast.**



The Calvin Cycle starts with RuBP molecules and carbon dioxide molecules. An enzyme called Rubisco combines them into an unstable intermediate.



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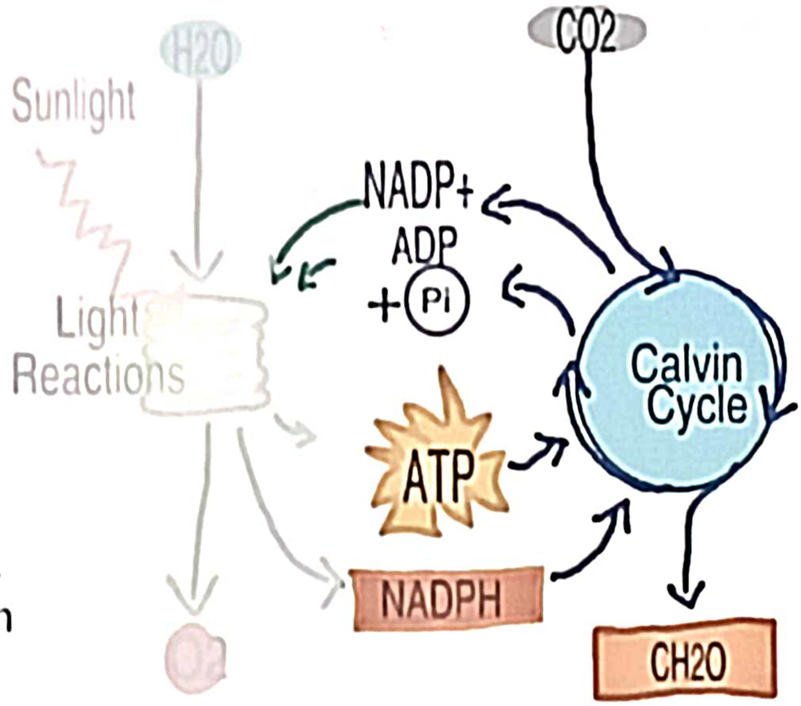

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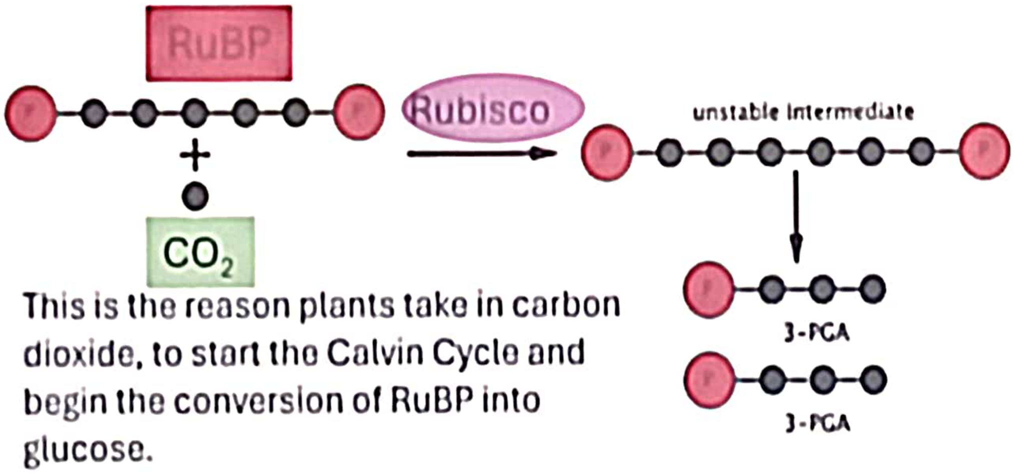
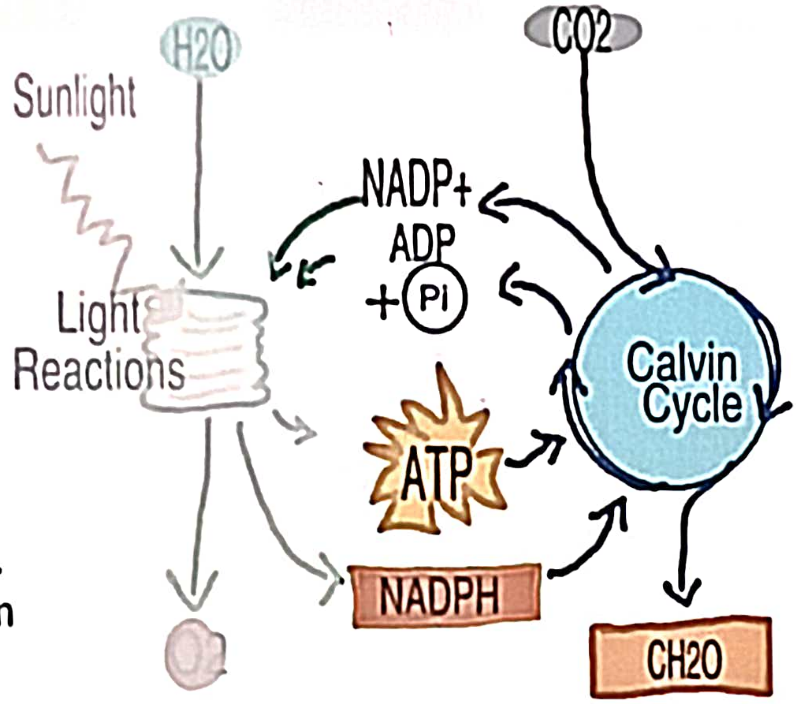


This is the reason plants take in carbon dioxide, to start the Calvin Cycle and begin the conversion of RuBP into glucose.

Dark Reaction



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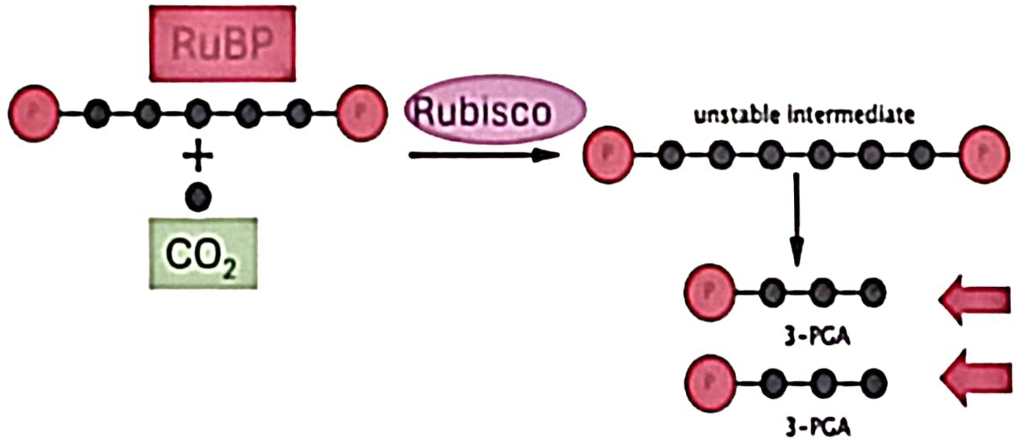
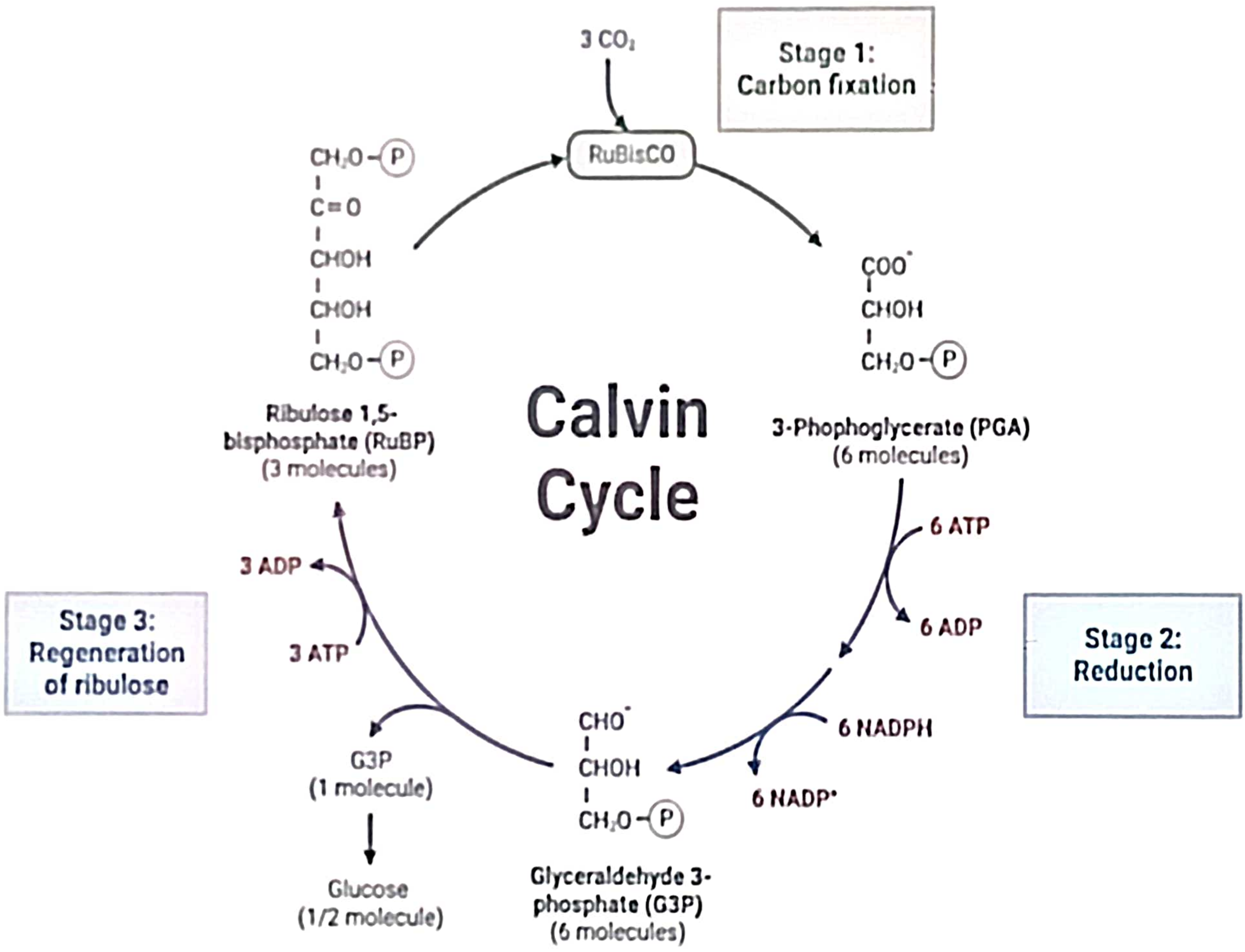
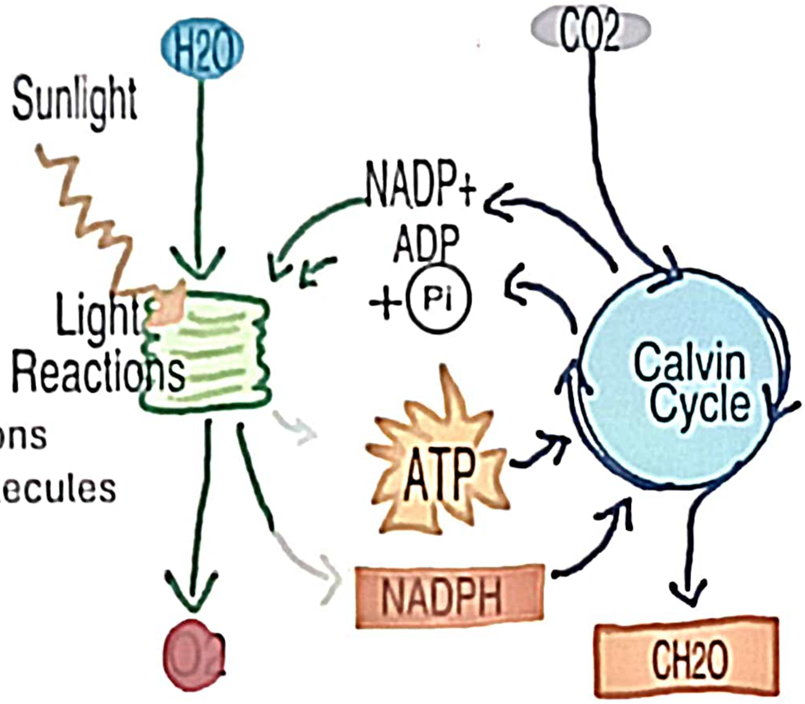


Since the intermediate of combined RuBP and CO_2 is unstable it quickly splits in half and forms 2 molecules of 3-PGA which are stable.

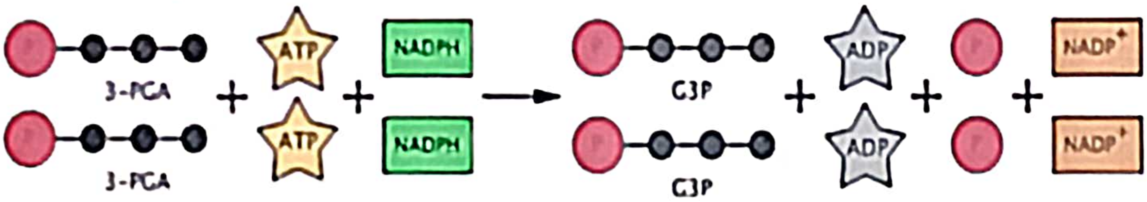


3 CO2
Stage 1:
Carbon fixation
RuBisCO
CH2O-P
C=O
CHOH
CHOH
CH2O-P
Ribulose 1,5-
bisphosphate (RuBP)
(3 molecules)
Calvin
Cycle
COO-
CHOH
CH2O-P
3-Phophoglycerate (PGA)
(6 molecules)
6 ATP
6 ADP
Stage 2:
Reduction
6 NADPH
6 NADP+
CHO-
CHOH
CH2O-P
Glyceraldehyde 3-
phosphate (G3P)
(6 molecules)
3 ADP
3 ATP
Stage 3:
Regeneration
of ribulose
G3P
(1 molecule)
Glucose
(1/2 molecule)

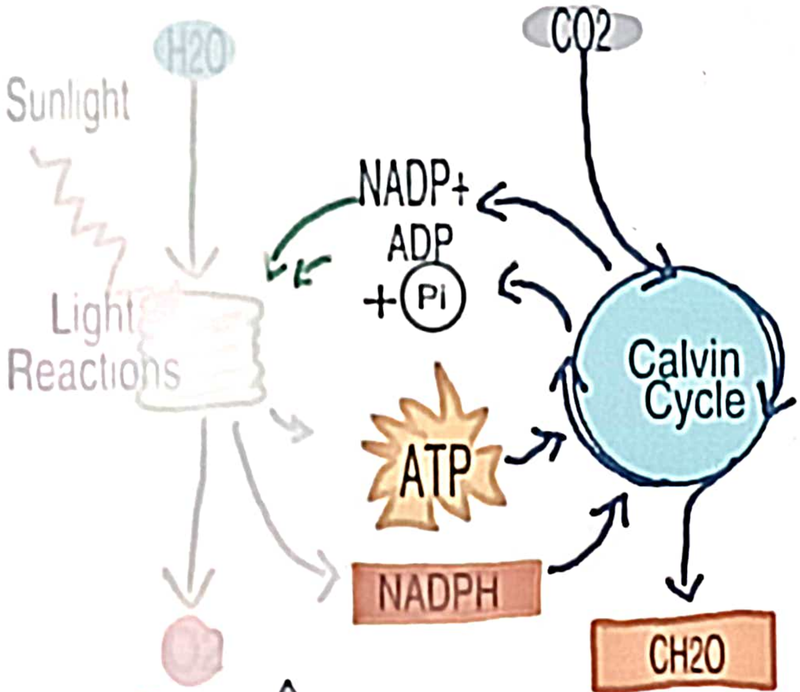
Dark Reactions



The ATP and NADPH from the light reactions provide the energy to convert the two molecules of 3-PGA into their final form.



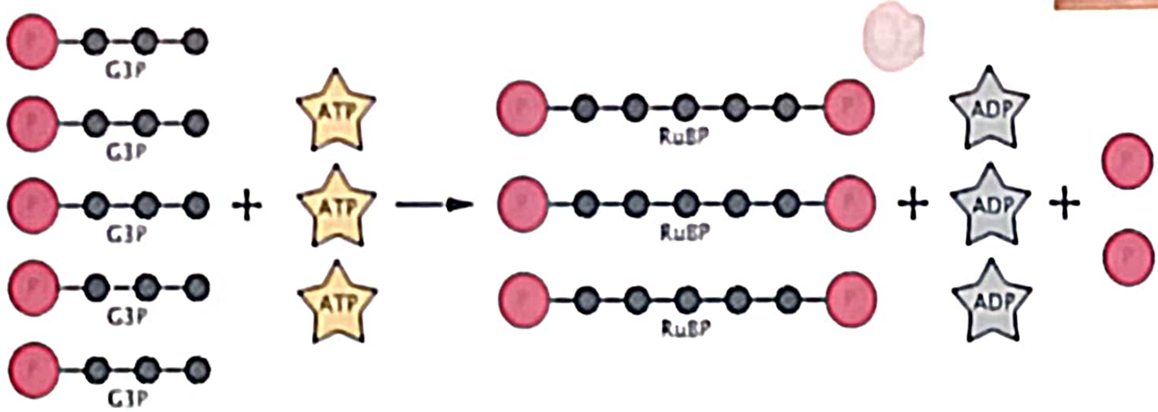
Dark Reactions



Not all G3P is made into glucose.

The Calvin Cycle occurs in every stroma in every chloroplast in every plant cell every second of every day.

That's a lot of reactions all happening simultaneously!

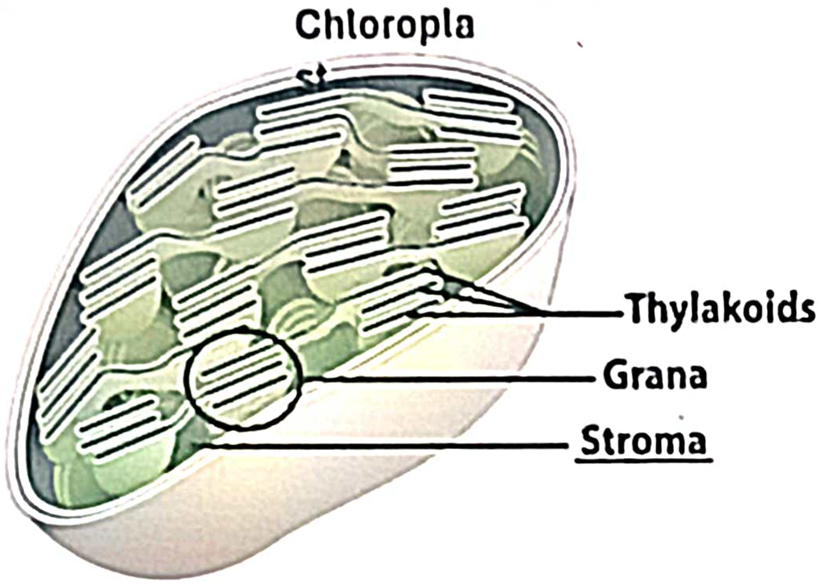


Most of the G3P made during the Calvin Cycle are made into RuBP, the starting molecule, with energy from ATP molecules.
Now the Calvin Cycle can begin again.

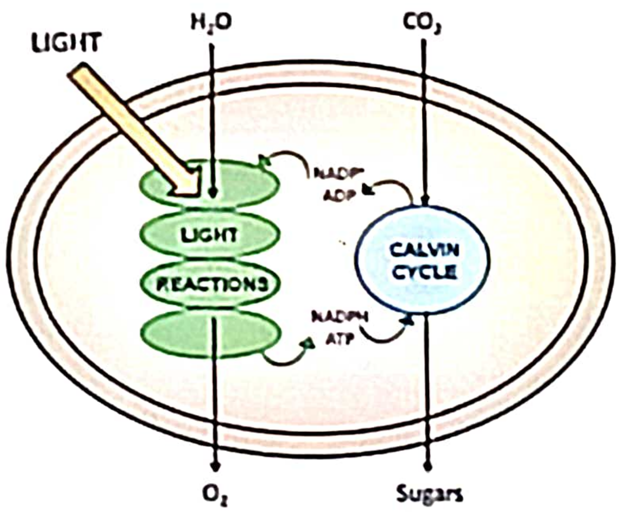
The spent ATP from the reaction leaves ADP and a phosphate group. These are reused in the light reactions to make more ATP.

Dark Reactions Summary

The Calvin Cycle converts the carbon from carbon dioxide into glucose in the stroma. This is called **carbon fixation** because carbon is fixed into another form.



Photosynthesis is carried out in two steps. First, in two light dependent photosystems. Second, in a light independent carbon fixation cycle called the Calvin Cycle. Through this process, the plant is able to convert sunlight, water, and CO_2 into glucose (or sugar) and ATP. As a byproduct of this process, O_2 is released.



Summary

- Plants are the producers of the biosphere creating the oxygen and glucose needed for most organisms.
- Chloroplasts are the site of photosynthesis in plants.
- Chloroplasts contain thylakoids where the light reactions take place.
- Light reactions convert sunlight into ATP and NADPH.
- The dark reactions or Calvin Cycle uses ATP and NADPH to convert CO_2 into sugar.
- The light reactions and the dark reactions cooperate to convert light energy into chemical energy housed in glucose.
- Plants and animals use glucose to power metabolic processes.