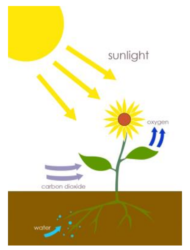
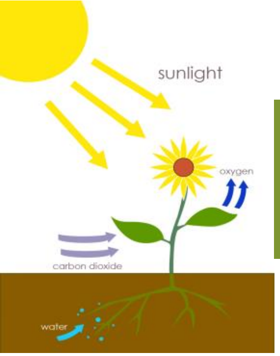
Photosynthesis: Light-Independent Reactions

- Photosynthesis takes place in two steps.
    - The Light Dependent Reaction.
    - Light Independent reaction (Dark Reaction).



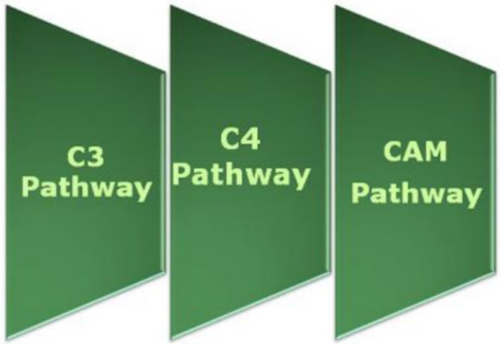
- The light reaction produce ATP and NADPH at site in the **Stroma** a in the dark reaction CO_2 is reduced/fixed with the help of ATP and NADPH to produce glucose.
- In dark reaction, two types of cyclic reaction occur. They are Calvin cycle or C3 cycle and Hatch Slack cycle or C4 cycle.



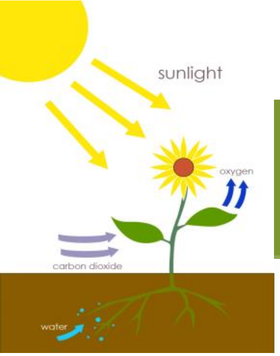
Photosynthesis: Light-Independent Reactions

Among terrestrial and aquatic autotrophs, there are three photosynthetic pathways to reduced the atmospheric CO_2 into organic forms;

- **Calvin cycle or C3 cycle and**
- **Hatch Slack cycle or C4 cycle**
- **Crassulacean acid metabolism (CAM)**

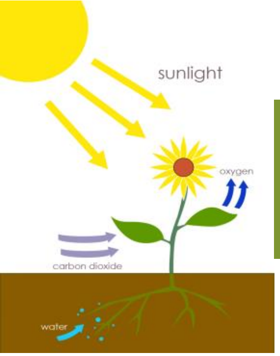


- C3 photosynthesis is the ancestral pathway for carbon fixation and occurs in all taxonomic plant groups.
- C4 photosynthesis occurs in the more advanced plant taxa and is especially common among monocots, such as grasses and sedges, but not very common among dicots (most trees and shrubs).
- CAM photosynthesis is sufficiently limited in distribution occurs in many epiphytes and succulents from very arid regions.



Photosynthesis: Light-Independent Reactions

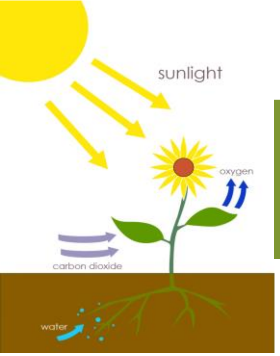
- The assimilation of **carbon dioxide** from the sunlight, for the process of photosynthesis and then converting it to **glucose (energy) synthesizing different product** is the key difference between the three.
- So during the CO_2 fixation, when the photosynthetic plants produce 3-phosphoglyceric acid (PGA) or 3- carbon acid as the first product is called **C3 pathway**.
- But when the photosynthetic plant, prior going to the C3 pathway, produces oxaloacetic acid (OAA) or 4 -carbon compound as their first stable product is called as **C4 or Hatch and Slack pathway**.
- But when the plants absorb the energy of the sunlight at the day time and use this energy for the assimilation or fixing the carbon dioxide at night time is called as **crassulacean acid metabolism or CAM**.



Photosynthesis: Light-Independent Reactions

Difference Between C3, C4 and CAM pathway

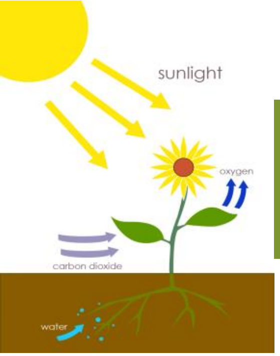
BASIS FOR COMPARISON	C3 PATHWAY	C4 PATHWAY	CAM
Definition	Such plants whose first product after the carbon assimilation from sunlight is 3-carbon molecule or 3-phosphoglyceric acid for the production of energy is called C3 plants, and the pathway is called as the C3 pathway. It is commonly used by plants.	Plants in the tropical area, convert the sunlight energy into C4 carbon molecule or oxaloacetice acid, which takes place before the C3 cycle and then it further convert into the energy, is called C4 plants and pathway is called as the C4 pathway. This is more efficient than the C3 pathway.	The plants which store the energy from the sun and then convert it into energy during night follows the CAM or crassulacean acid metabolism.
Cells involved	Mesophyll cells.	Mesophyll cell, bundle sheath cells.	Both C3 and C4 in same mesophyll cells.
Example	Sunflower, Spinach, Beans, Rice, Cotton.	Sugarcane, Sorghum and Maize.	Cacti, orchids.



Photosynthesis: Light-Independent Reactions

Difference Between C3, C4 and CAM pathway

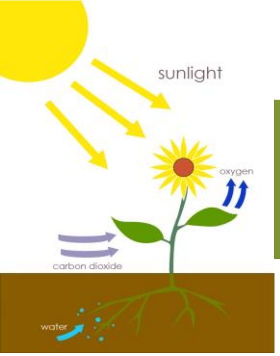
BASIS FOR COMPARISON	C3 PATHWAY	C4 PATHWAY	CAM
Can be seen in	All photosynthetic plants.	In tropical plants	Semi-arid condition.
Types of plants using this cycle	Mesophytic, hydrophytic, xerophytic.	Mesophytic.	Xerophytic.
Photorespiration	Present in high rate.	Not easily detectable.	Detectable in the afternoon.
For the production of glucose	12 NADPH and 18 ATPs are required.	12 NADPH and 30 ATPs are required.	12 NADPH and 39 ATPs are required.
First stable product	3-phosphoglycerate (3-PGA).	Oxaloacetate (OAA).	Oxaloacetate (OAA) at night, 3 PGA at daytime.
Calvin cycle operative	Alone.	Along with the Hatch and Slack cycle.	C3 and Hatch and Slack cycle.



Photosynthesis: Light-Independent Reactions

Difference Between C3, C4 and CAM pathway

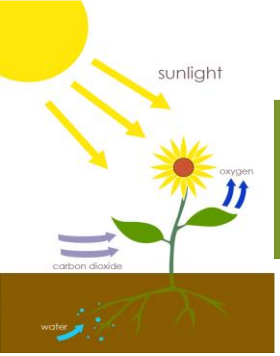
BASIS FOR COMPARISON	C3 PATHWAY	C4 PATHWAY	CAM
Optimum temperature for photosynthesis	15-25 °C	30-40 °C	> 40 degrees °C
Carboxylating Enzyme	RuBP carboxylase.	In mesophyll: PEP carboxylase. In bundle sheath: RuBP carboxylase.	In the dark: PEP carboxylase. In light: RUBP carboxylase.
CO_2: ATP: $NADPH_2$ ratio	1:3:2	1:5:2	1:6.5:2
Initial CO_2 acceptor	Ribulose-1,5-biphophate(RuBP).	Phosphoenolpyruvate (PEP).	Phosphoenolpyruvate (PEP).
Kranz Anatomy	Absent.	Present.	Absent.
CO_2 compensation point (ppm)	30-70.	6-10.	0-5 in dark.



Photosynthesis: Light-Independent Reactions

The Calvin cycle ' the classic pathway of photosynthesis

- The **Calvin cycle** (also known as the **Benson-Calvin cycle**) is the set of chemical reactions that take place in chloroplasts during Photosynthesis.
- The cycle is light-independent because it takes place after the energy has been captured from sunlight.
- The Calvin cycle is named after Melvin C. Calvin, who won a Nobel Prize in Chemistry for finding it in 1961. Calvin and his colleagues, Andrew Benson and James Bassham, did the work at the University of California, Berkeley.



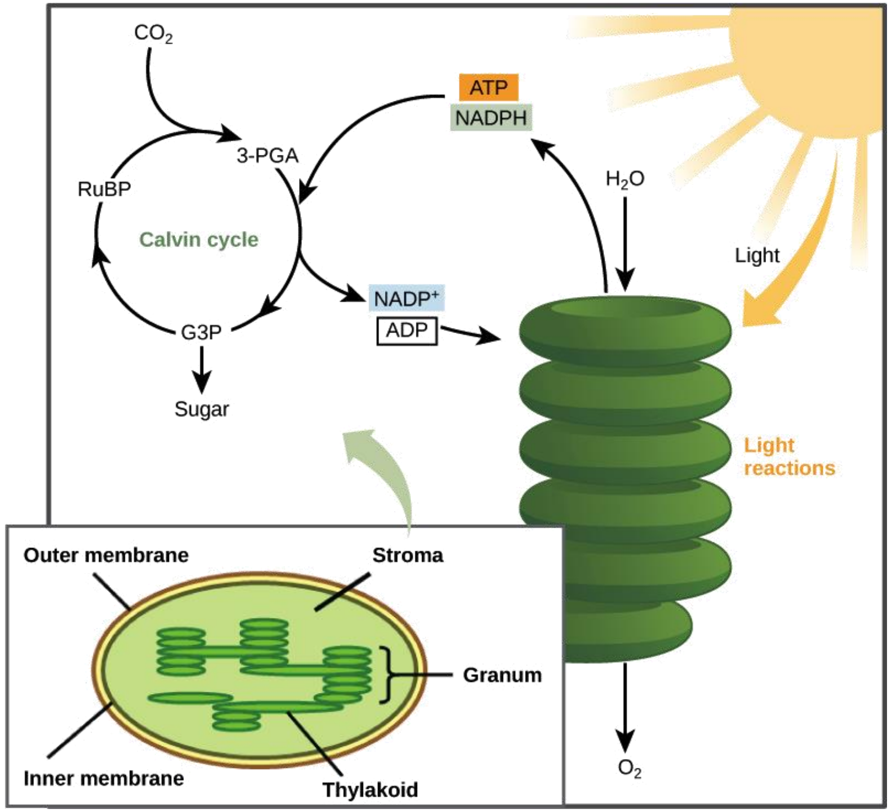
Photosynthesis: Light-Independent Reactions

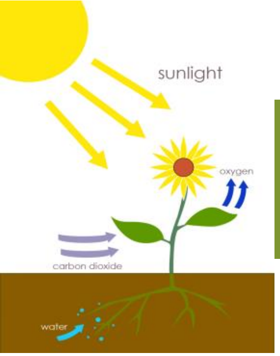
The Calvin cycle ‘ the classic pathway of photosynthesis

In plants, carbon dioxide (CO_2) enters the interior of a leaf via pores called stomata and diffuses into the stroma of the chloroplast—the site of the **Calvin cycle** reactions, where sugar is synthesized. These reactions are also called the **light-independent** reactions because they are not directly driven by light.

In the Calvin cycle, carbon atoms from CO_2 are fixed (incorporated into organic molecules) and used to build three-carbon sugars. This process is fueled by, and dependent on, ATP and NADPH from the light reactions.

Unlike the light reactions, which take place in the thylakoid membrane, the reactions of the Calvin cycle take place in the stroma (the inner space of chloroplasts).

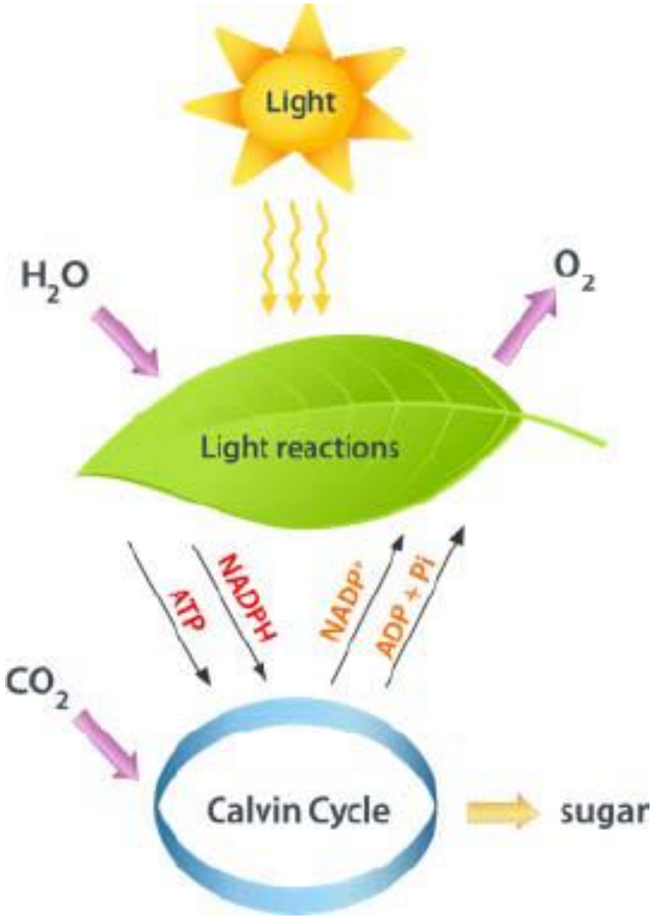


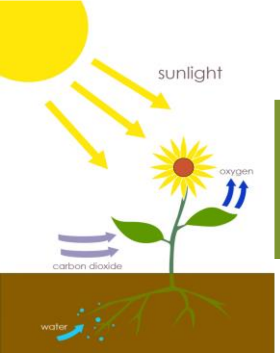


Photosynthesis: Light-Independent Reactions

Calvin Cycle: Features

- Light-Independent Reactions, or the Calvin cycle, produces six carbon glucose molecules.
- The Calvin cycle does not need sun light because it uses energy from ATP and NADPH molecules that were created in Light-Dependent Reactions.
- Carbon atoms started out as a carbon atom in a carbon dioxide. Then, the energy from ATP and NADPH molecules are used to convert carbon dioxide molecules into carbohydrate molecules.





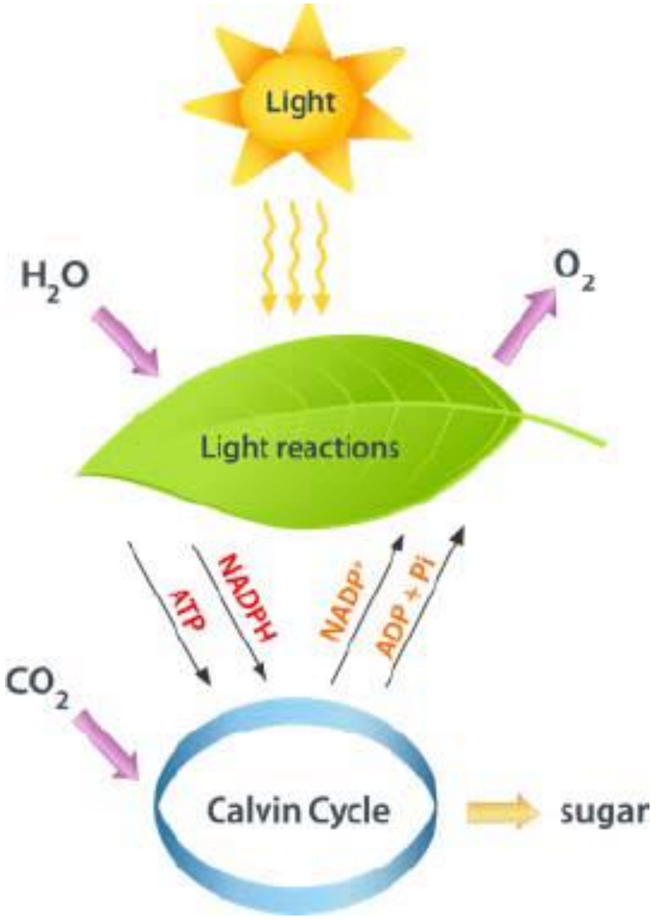
Photosynthesis: Light-Independent Reactions

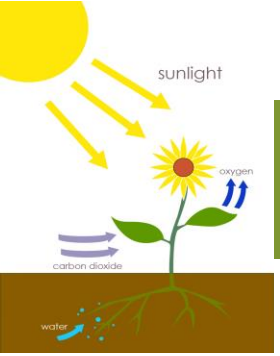
Calvin Cycle: Features

- Then, other carbon dioxide molecules enter the Calvin cycle from the atmosphere.

- An enzyme from the chlorophyll combines the carbon dioxide molecules from the atmosphere with carbohydrate molecules, such as the one carbon atom is part of now, to make three- carbon compounds.

- Out of 12 three carbon molecules, two are removed to build organic material Carbon atom is part of a three-carbon molecule that has been removed and bonded together with another removed molecule to make a six-carbon sugar, glucose.





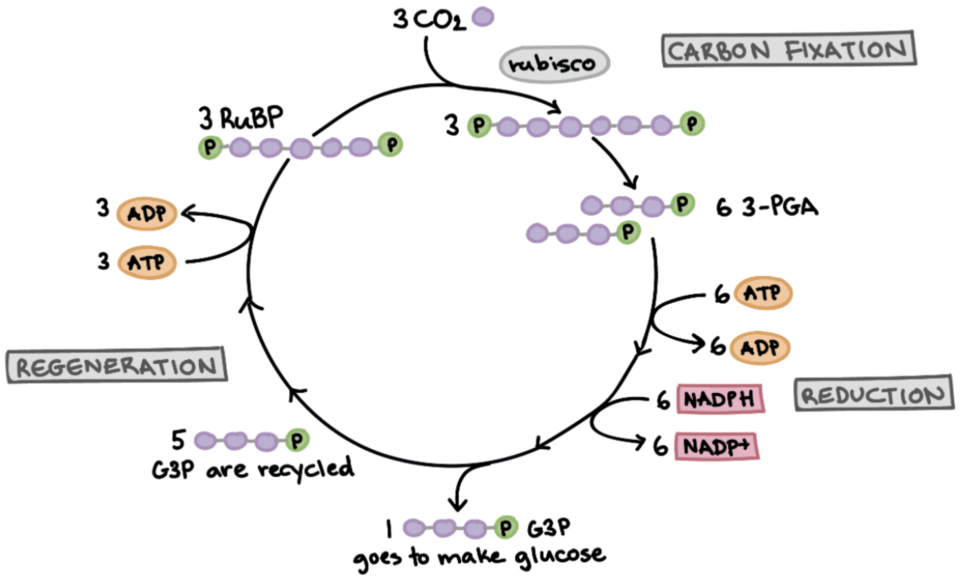
Photosynthesis: Calvin Cycle

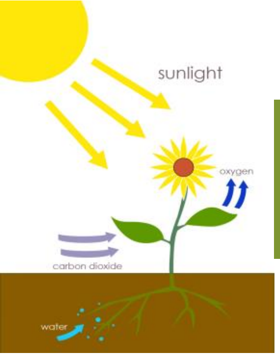
Reactions of the Calvin cycle

There are three phases to the light-independent reactions, collectively called the Calvin cycle: carbon fixation, reduction reactions, and ribulose 1,5-bisphosphate (RuBP) regeneration..

Here is a general diagram of the cycle:

The cycle was discovered by Melvin Calvin, James Bassham, and Andrew Benson at the University of California, Berkeley by using the radioactive isotope carbon

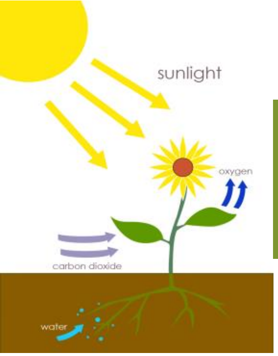




Photosynthesis: Calvin Cycle

Carbon fixation:

A CO_2 molecule combines with a five-carbon acceptor molecule, ribulose-1,5-bisphosphate (**RuBP**). This step makes a six-carbon compound that splits into two molecules of a three-carbon compound, 3-phosphoglyceric acid (3-PGA). This reaction is catalyzed by the enzyme RuBP carboxylase/oxygenase, or **rubisco**.

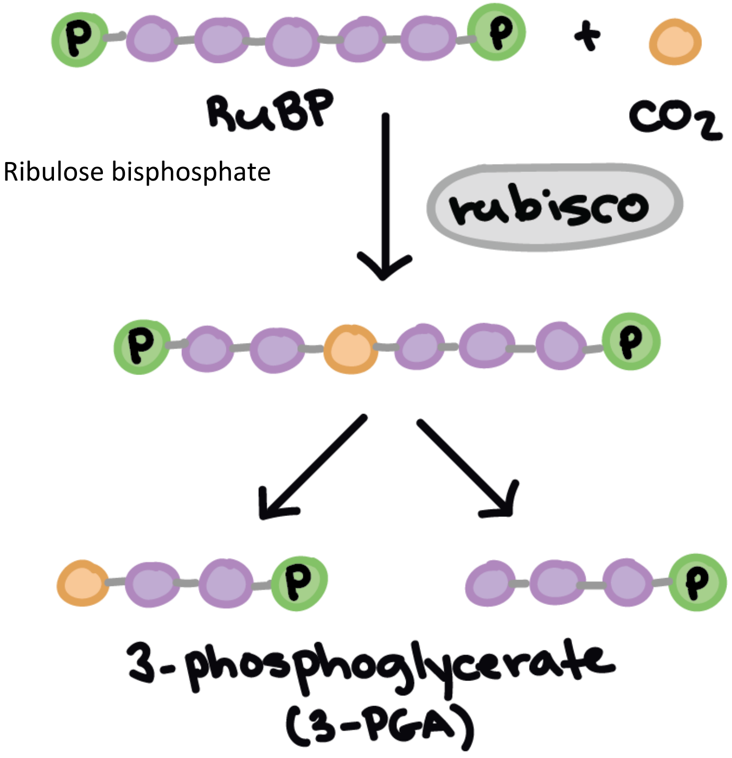


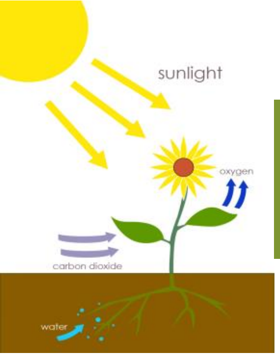
Photosynthesis: Calvin Cycle

Carbon fixation:

The first stage of the Calvin cycle incorporates carbon from CO_2 into an organic molecule, a process called **carbon fixation.** In plants, atmospheric CO_2 enters the mesophyll layer of leaves by passing through pores on the leaf surface called stomata. It can then diffuse into mesophyll cells, and into the stroma of chloroplasts, where the Calvin cycle takes place.

In the first step of the cycle, an enzyme nicknamed **rubisco** (RuBP carboxylase-oxygenase) catalyzes attachment of CO_2 to a five-carbon sugar called **ribulose bisphosphate (RuBP**). The resulting 6-carbon molecule is unstable, however, and quickly splits into two molecules of a three-carbon compound called 3-phosphoglycerate (3-PGA). Thus, for each CO_2 that enters the cycle, two 3-PGA molecules are produced.

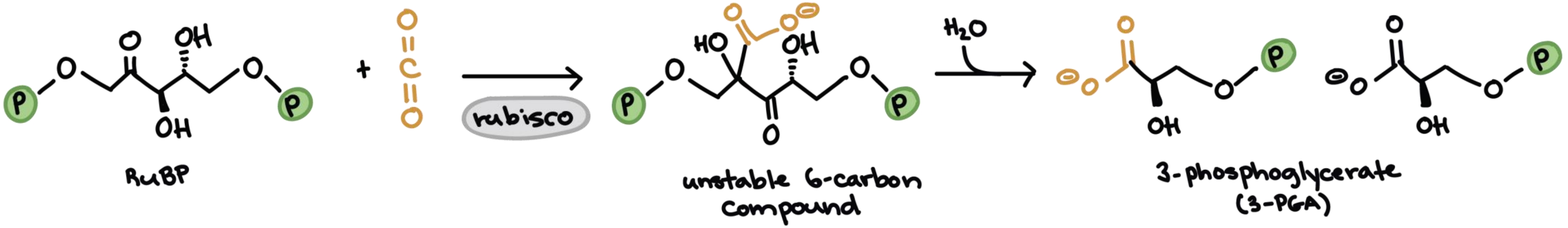


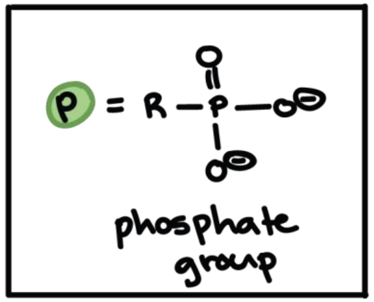


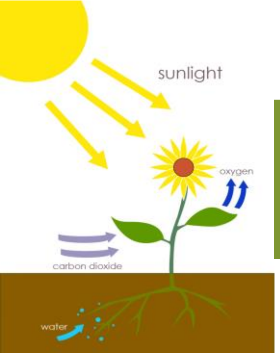
Photosynthesis: Calvin Cycle

Carbon fixation:

The actual molecular structures are given below:



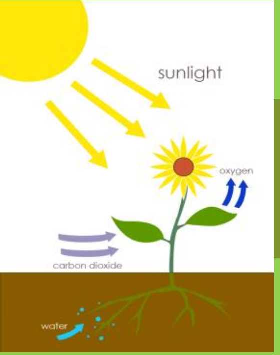




Photosynthesis: Calvin Cycle

Reduction:

In the second stage, ATP and NADPH are used to convert the 3-PGA molecules into molecules of a three-carbon sugar, glyceraldehyde-3-phosphate (**G3P**). This stage gets its name because NADPH donates electrons to, or **reduces**, a three-carbon intermediate to make G3P.

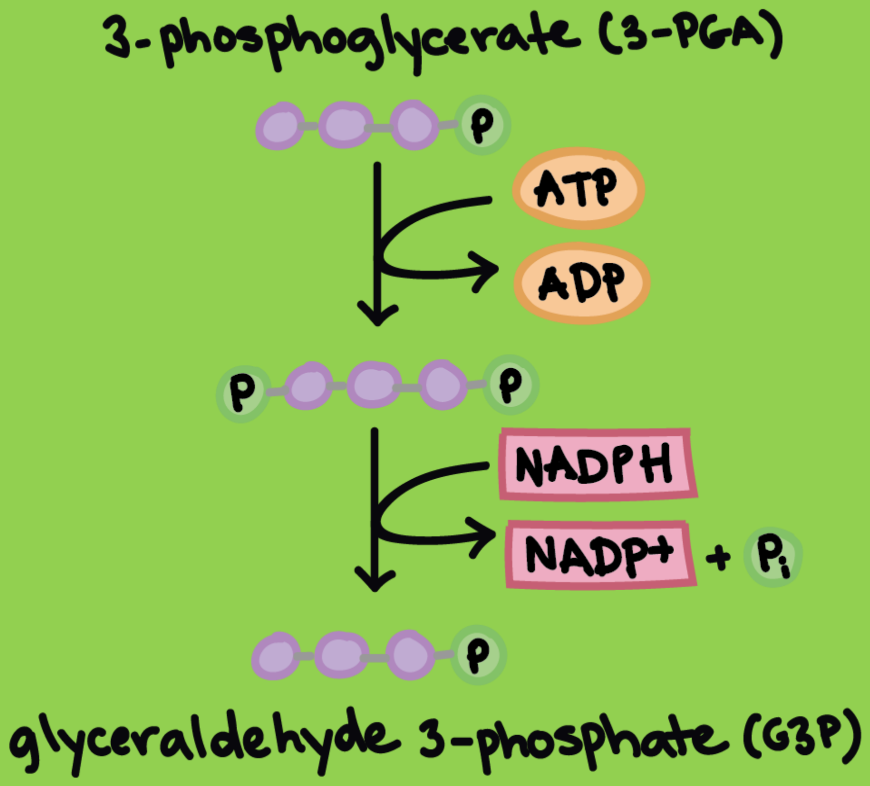


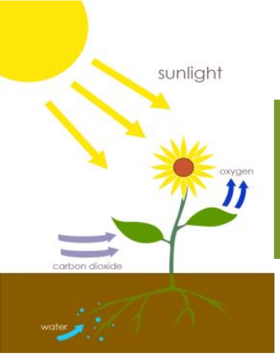
Photosynthesis: Calvin Cycle

Reduction:

The reduction stage of the Calvin cycle, which requires ATP and NADPH, converts 3-PGA (from the fixation stage) into a three-carbon sugar. This process occurs in two major steps:

- First, each molecule of 3-PGA receives a phosphate group from ATP, turning into a doubly phosphorylated molecule called 1,3-bisphosphoglycerate (and leaving behind ADP as a by-product).
- Second, the 1,3-bisphosphoglycerate molecules are reduced (gain electrons). Each molecule receives two electrons from NADPH and loses one of its phosphate groups, turning into a three-carbon sugar called **glyceraldehyde 3-phosphate (G3P)**. This step produces NADP+ and phosphate (P*i*) as by-products.

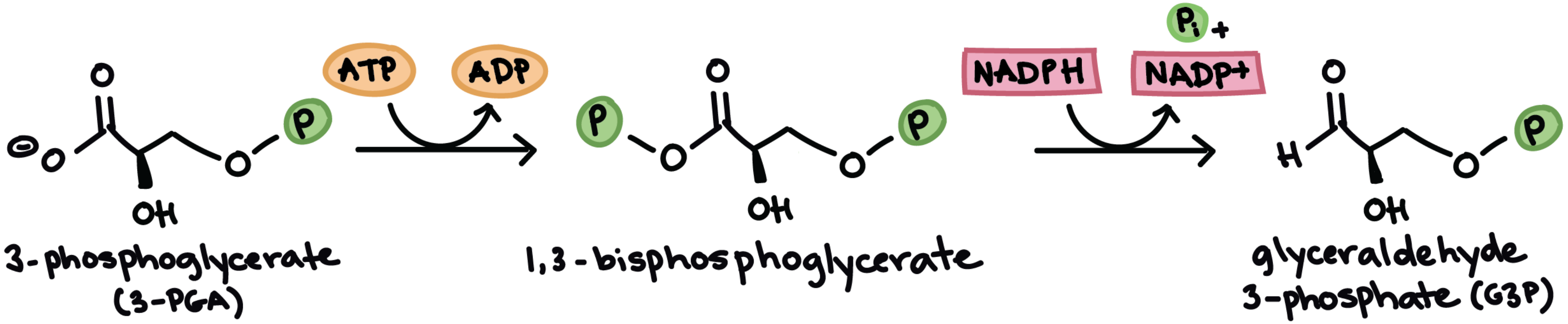


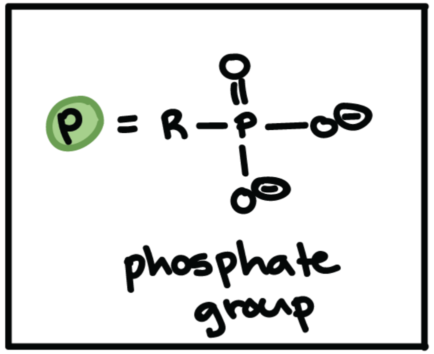


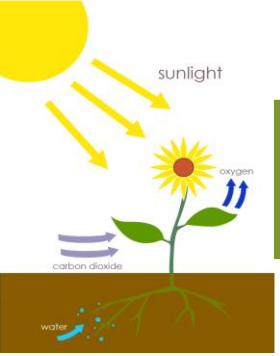
Photosynthesis: Calvin Cycle

Carbon fixation:

The actual chemical structures are given below:



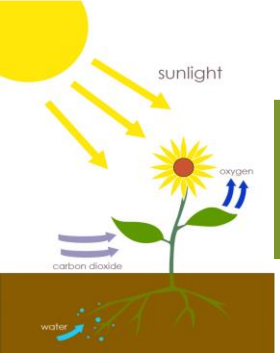




Photosynthesis: Calvin Cycle

Regeneration:

Some G3P molecules go to make glucose, while others must be recycled to regenerate the RuBP acceptor. Regeneration requires ATP and involves a complex network of reactions.



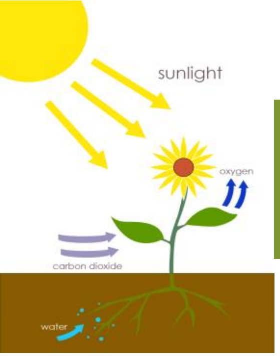
Photosynthesis: Calvin Cycle

Regeneration:

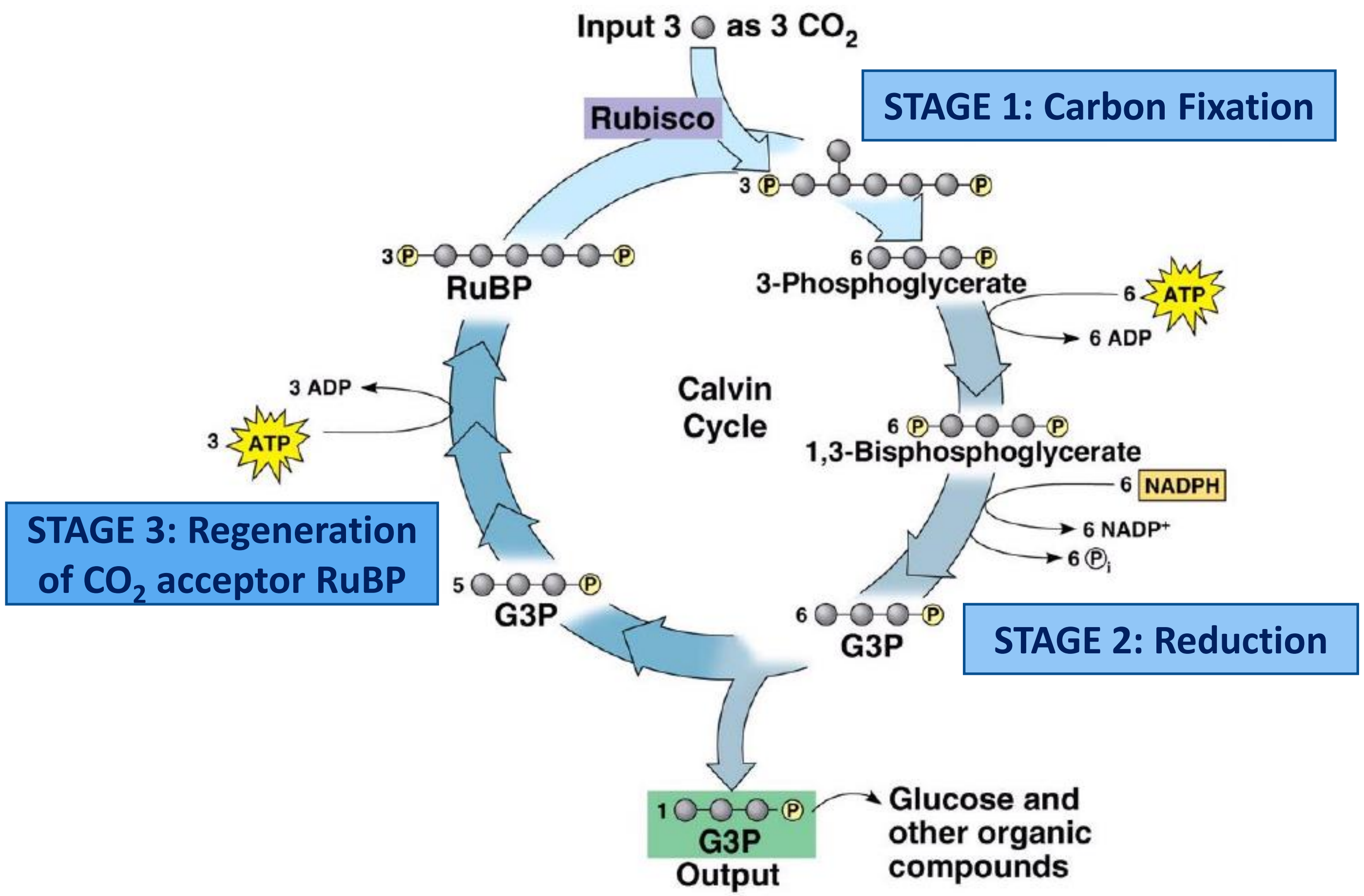
In order of one G3P to exit the cycle (and go towards glucose synthesis), three CO_2 must enter the cycle, providing three new atoms of fixed carbon.

When three CO_2 molecules enter the cycle, six G3P molecules are made.

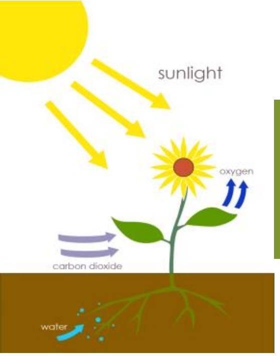
One exits the cycle and is used to make glucose, while the other five must be recycled to regenerate three molecules of the RuBP acceptor.



Photosynthesis: Calvin Cycle



Note: For net photosynthesis of 1 G3P the cycle must take place three times, fixing 3 molecules of CO_2



Photosynthesis: Calvin Cycle

Energy expenditure

Three ATP and two NADPH molecules are used to bring carbon dioxide to the level of a hexose.

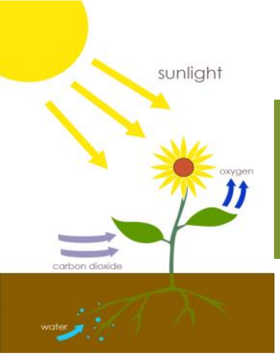
What is the energy expenditure for synthesizing a hexose?

Six rounds of the Calvin cycle are required, because one carbon atom is reduced in each round. Twelve molecules of ATP are expended in phosphorylating 12 molecules of 3-phosphoglycerate to 1,3-bisphosphoglycerate, and 12 molecules of NADPH are consumed in reducing 12 molecules of 1,3-bisphosphoglyc-erate to glyceraldehyde 3-phosphate. An additional six molecules of ATP are spent in regenerating ribulose 1,5-bisphosphate.

Now the balanced equation for the net reaction of the Calvin cycle is;

$$6\,CO_2 + 18\,ATP + 12\,NADPH + 12\,H_2O \longrightarrow C_6H_{12}O_6 + 18\,ADP + 18\,P_i + 12\,NADP^+ + 6\,H^+$$

Thus, three molecules of ATP and two molecules of NADPH are consumed in incorporating a single CO_2 molecule into a hexose such as glucose or fructose



Photosynthesis: Calvin Cycle

Summary of Calvin cycle reactants and products

- Three turns of the Calvin cycle are needed to make one G3P molecule that can exit the cycle and go towards making glucose. Let's summarize the quantities of key molecules that enter and exit the Calvin cycle as one net G3P is made. In three turns of the Calvin cycle:
- **Carbon.** 3CO_2 combine with 3RuBP acceptors, making 6 molecules of glyceraldehyde-3-phosphate (G3P).
  - 1 G3P molecule exits the cycle and goes towards making glucose.
  - 5 G3P molecules are recycled, regenerating 3 RuBP acceptor molecules.
- **ATP.** 9 ATP are converted to 9 ADP (6 during the fixation step, 3 during the regeneration step).
- **NADPH**. 6 NADPH are converted to 6 NADP+ (during the fixation step).
- A G3P molecule contains three fixed carbon atoms, so it takes two G3Ps to build a six-carbon glucose molecule. It would take six turns of the cycle, or 6CO_2, 18 ATP, and 12 NADPH, to produce one molecule of glucose.