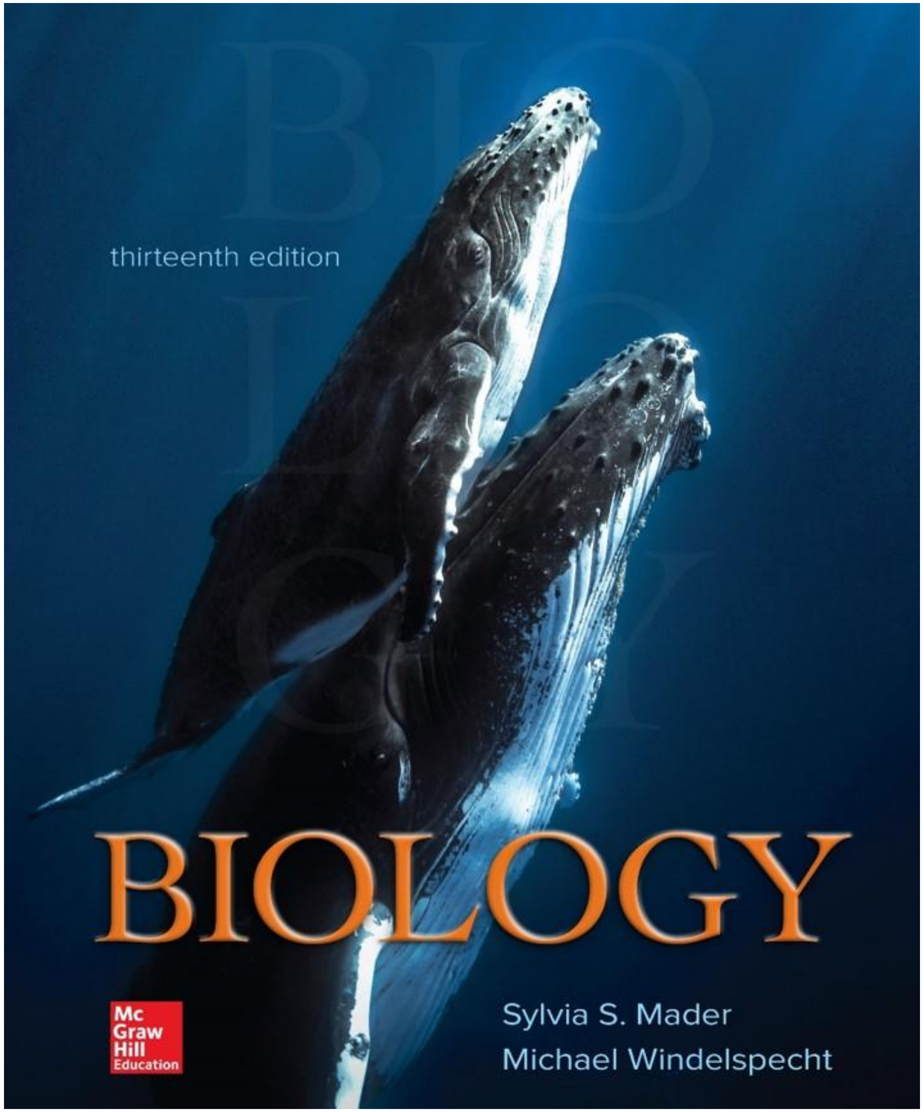


Biology

Sylvia S. Mader
Michael Windelspecht

Chapter 7
Photosynthesis
Lecture Outline

See separate FlexArt PowerPoint slides for all figures and tables pre-inserted into PowerPoint without notes.

Outline

Photosynthesis as the Key to Solving Our Fuel Crisis

Plant scientists are tweaking the basic chemistry of photosynthesis to create commercially important oils and fuels.

An example is Carmelina, a drought-resistant oilseed crop.

- Scientists are improving the efficiency of photosynthesis using genetic engineering.
- They are also improving CO_2 absorption to increase the raw materials for oil production.

Another example is terpene, a high-energy organic molecule from pine trees that makes turpentine.

- Scientists are increasing terpene production to use in making aviation biofuels.

7.1 Photosynthetic Organisms

All life on Earth depends on solar energy.

Photosynthetic organisms (algae, plants, and cyanobacteria) transform solar energy into the chemical energy of carbohydrates.

- Called **autotrophs** because they produce their own food

Photosynthesis:

- A process that captures solar energy
- Transforms solar energy into chemical energy
- Energy ends up stored in a carbohydrate

Photosynthesizers produce food energy.

- Feed themselves as well as **heterotrophs**
  - Heterotrophs are also known as consumers.
- Both autotrophs and heterotrophs use organic molecules produced by photosynthesis as a source of chemical energy for cellular work.

Think, Pair, Share

- What is an organism called if it can make it’s own food supply from scratch?
- What groups of species are able to do this?

7-5

Photosynthetic Organisms (1)

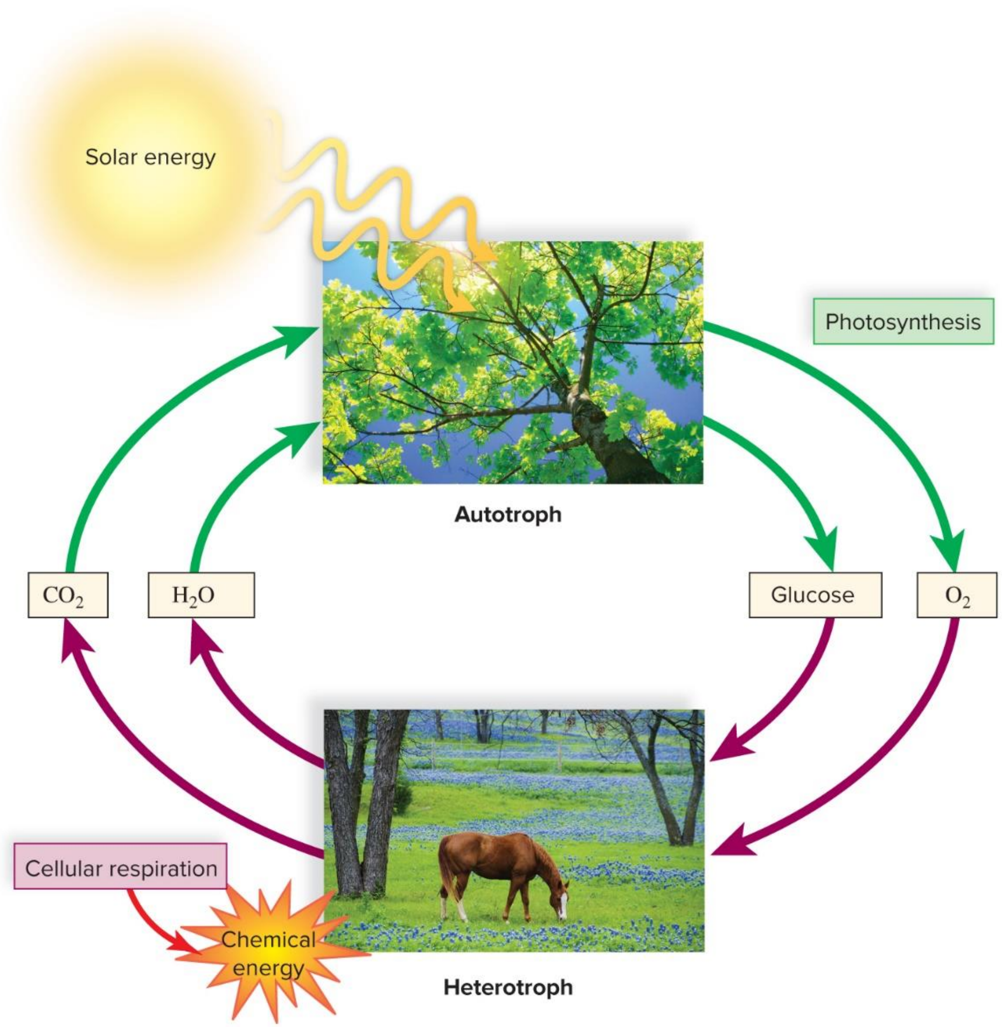
Photosynthesis takes place in the green portions of plants.

- The leaf of the flowering plant contains mesophyll tissue.
- Cells containing **chloroplasts** are specialized to carry out photosynthesis.

The raw materials for photosynthesis are carbon dioxide and water.

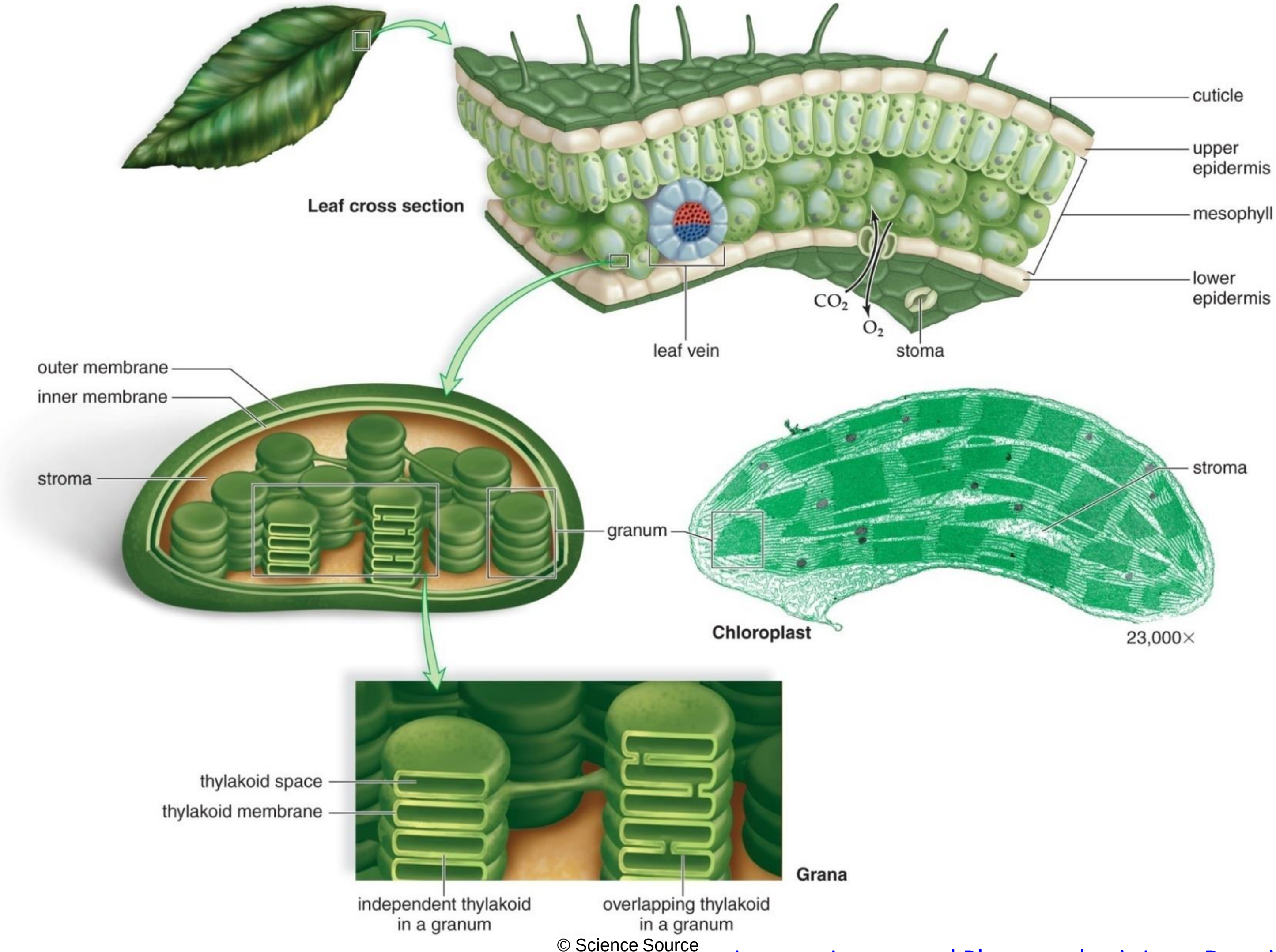
- Roots absorb water that moves up vascular tissue.
- Carbon dioxide enters a leaf through small openings called **stomata** and diffuses into chloroplasts in mesophyll cells.
- The thylakoid membranes of chloroplasts contain chlorophyll and other pigments that can absorb the solar energy that drives photosynthesis.
- Electrons are energized in the process.
- Then, carbon dioxide is reduced to form a carbohydrate.
- In the stroma, CO_2 combines with H_2O to form $C_6H_{12}O_6$ (sugar).

Photosynthetic Organisms (2)



(photos): (autotroph): ©Design Pics/Don Hammond RF; (heterotroph): ©Jeff R. Clow/Getty RF

Leaves and Photosynthesis



[Jump to Leaves and Photosynthesis Long Description](#)

7.2 The Process of Photosynthesis

Light reactions take place only in the presence of light.

- They are energy-capturing reactions.
- Chlorophyll absorbs solar energy.
  - This energizes electrons.
- Electrons move down an electron transport chain.
  - The electron transport chain pumps H^+ into thylakoids.
  - The electron transport chain is used to make ATP out of ADP, and NADPH out of NADP.

Calvin cycle reactions take place in the stroma.

- CO_2 is reduced to a carbohydrate.
- Reactions use ATP and NADPH to produce carbohydrate.
- Reactions were named after Melvin Calvin, who used a carbon isotope to trace carbon in photosynthesis.

Photosynthesis involves oxidation and reduction.

- Oxidation is the loss of, and reduction of, the gain of electrons.
- In photosynthesis, carbon dioxide is reduced and water oxidized.

Think, Pair Share

- What does the movement of electrons create?
- What is the electron transport chain used to accomplish in a thylakoid?

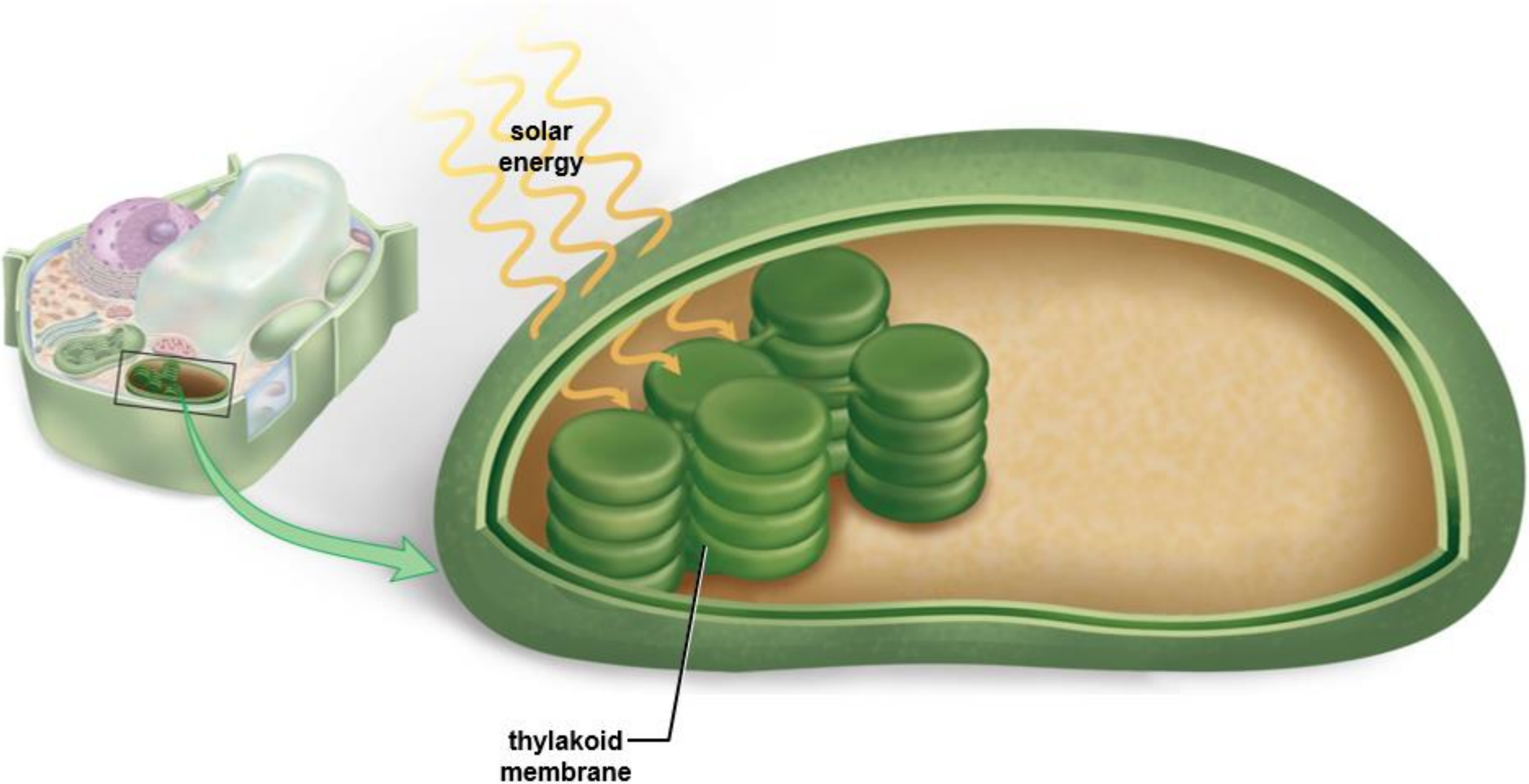
7-10

Photosynthesis Releases Oxygen

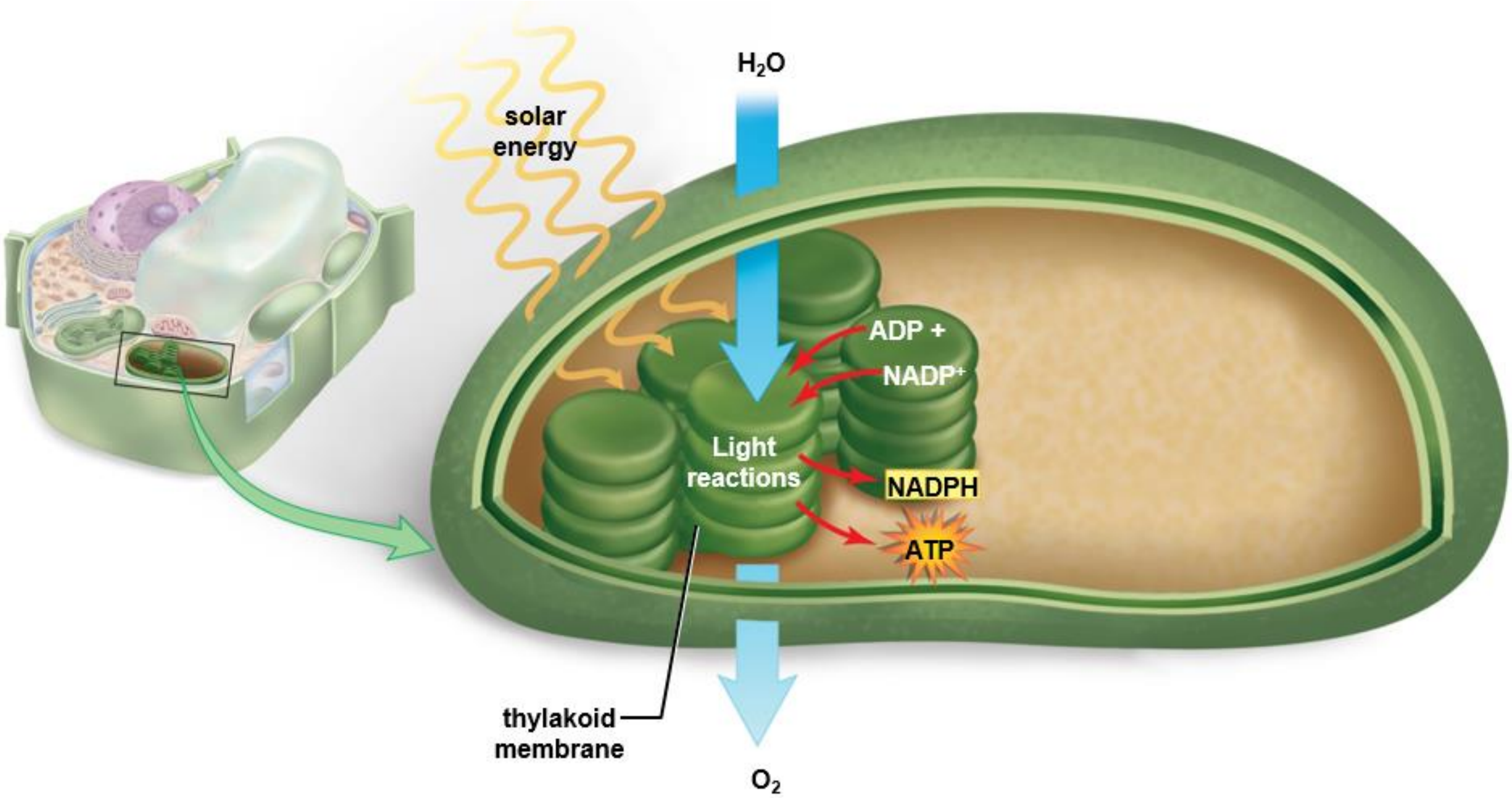
© Nigel Cattlin/Science Source

Jump to Photosynthesis Releases Oxygen Long Description

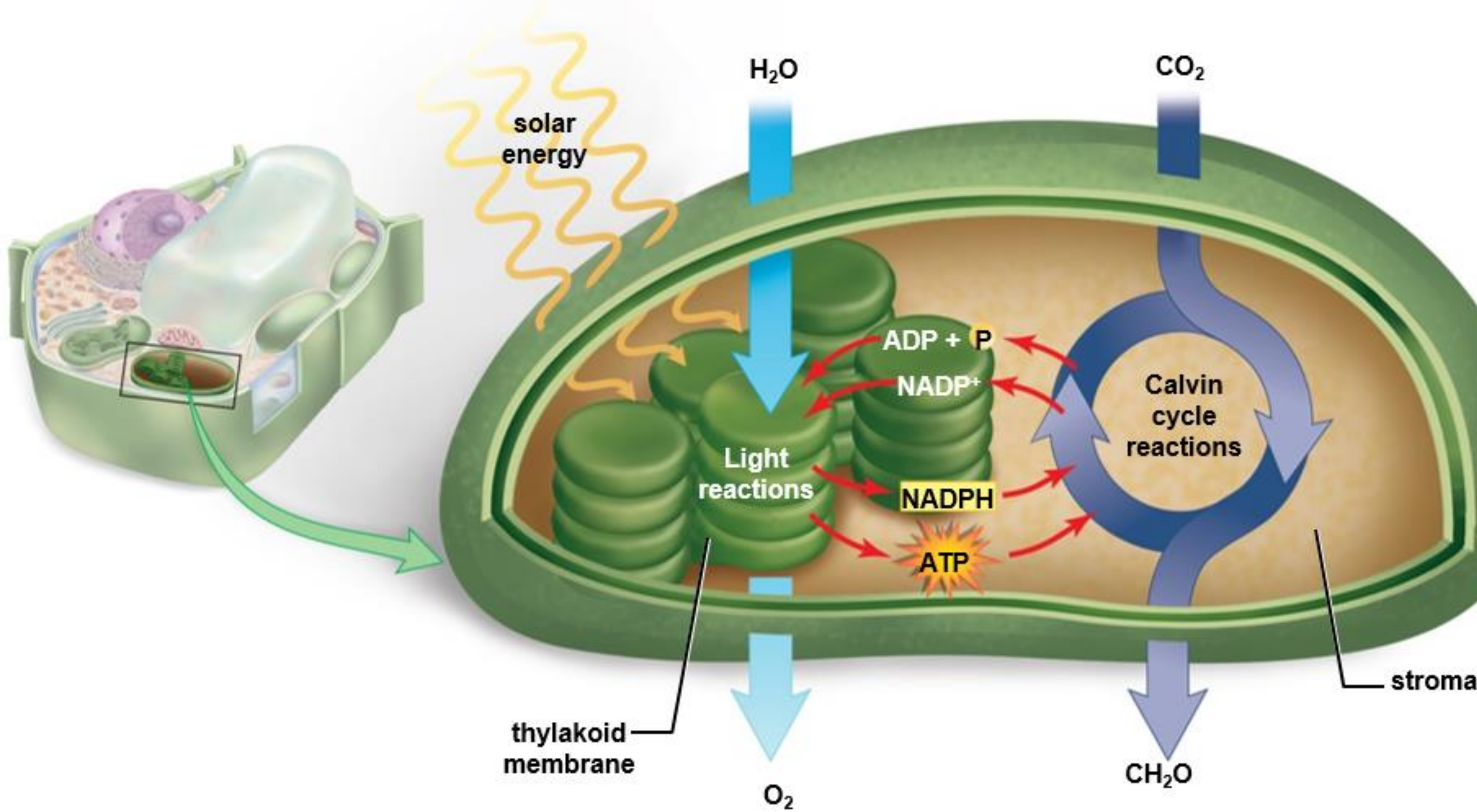
Overview of Photosynthesis (1)



Overview of Photosynthesis (2)



Overview of Photosynthesis (3)



Jump to Overview of Photosynthesis (3) Long Description

7.3 Plants Convert Solar Energy

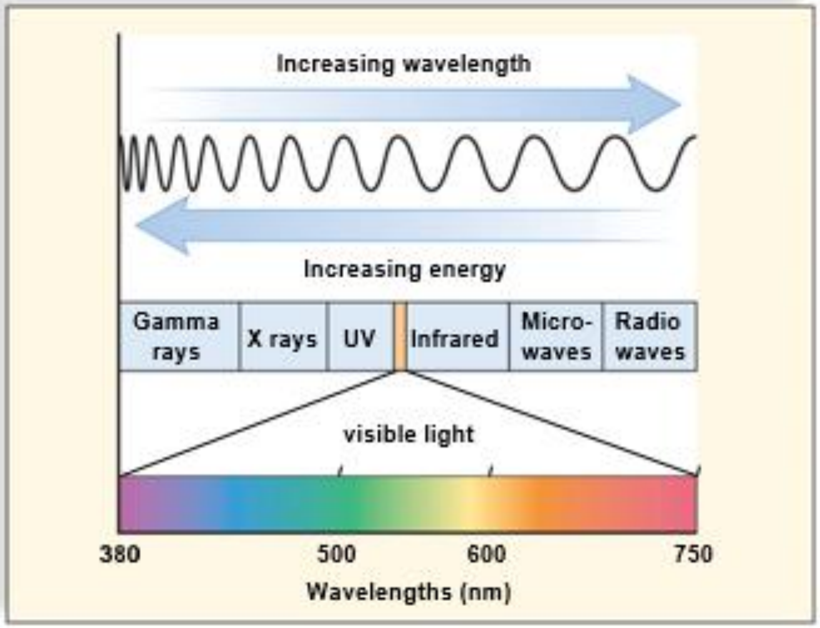
Pigments and photosystems:

- Chemicals that absorb certain wavelengths of light are pigments.
- Wavelengths that are not absorbed by pigments are reflected or transmitted.

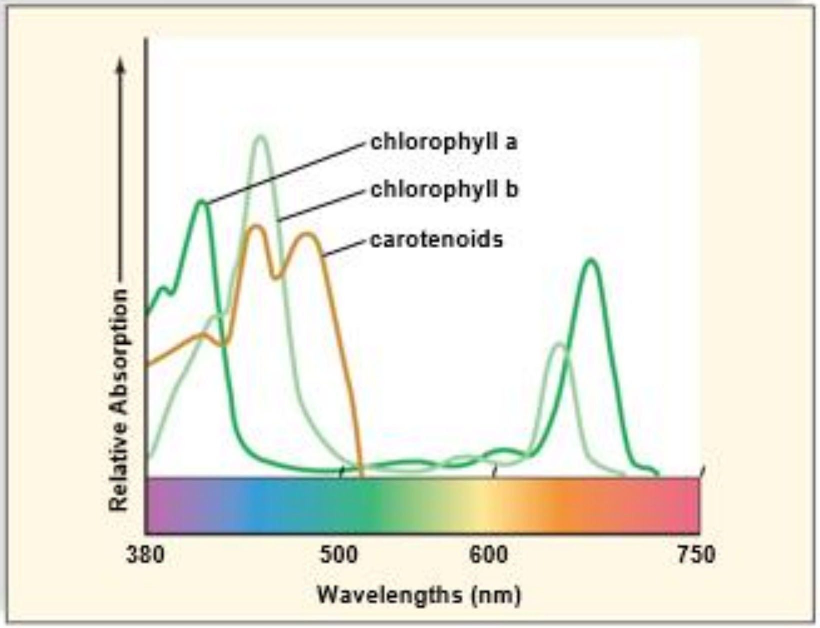
Absorption spectrum

- Pigments found in chlorophyll absorb various portions of visible light.
- An absorption spectrum is a graph showing relative absorption of the various colors of the rainbow.
- Chlorophyll is green because it absorbs much of the reds and blues of white light and reflects green light.
  - Carotenoids are accessory pigments which absorb light in the violet-blue-green range and reflect yellow and orange light.

Photosynthetic Pigments and Photosynthesis



a. The electromagnetic spectrum includes visible light.



b. Absorption spectrum of photosynthetic pigments.

[Jump to Photosynthetic Pigments and Photosynthesis Long Description](#)

Think, Pair, Share

- Is chlorophyll the only photosynthetic pigment?

7-17

Plants Convert Solar Energy (1)

The light reactions consist of two alternate electron pathways:

- Noncyclic pathway
- Cyclic pathway

Light reactions capture light energy with photosystems (there are two, I and II).

- A photosystem is a pigment complex that helps collect solar energy, like an antenna.
- Photosystems are located in the thylakoid membranes.

Both cyclic and noncyclic pathways produce ATP.

The noncyclic pathway also produces NADPH.

Plants Convert Solar Energy (2)

Noncyclic pathway:

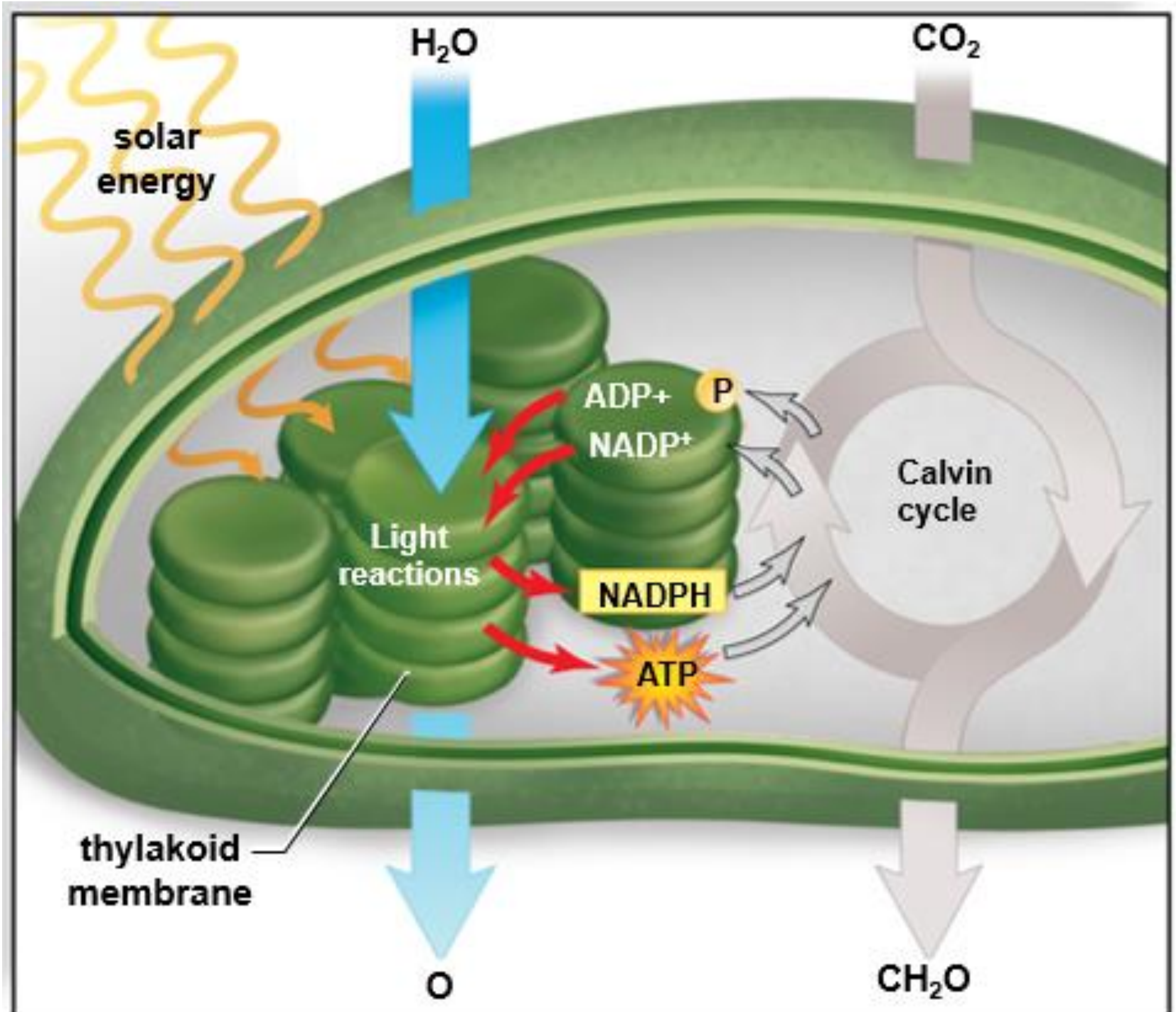
- Takes place in the thylakoid membrane
- Uses two photosystems: PS I and PS II
- PS II captures light energy
- Noncyclic pathway begins with photosystem II
- Causes an electron to be ejected from the reaction center (chlorophyll *a*)
  - Electron travels down **electron transport chain** to PS I
  - Replaced with an electron from water, which is split to form O_2 and H^+
  - This causes H^+ to accumulate in thylakoid chambers (inside).
  - The H^+ gradient is used to produce ATP.
- PS I captures light energy and ejects an electron.
  - The electron is transferred *permanently* to a molecule of $NADP^+$.
  - Causes NADPH production

Think, Pair, Share

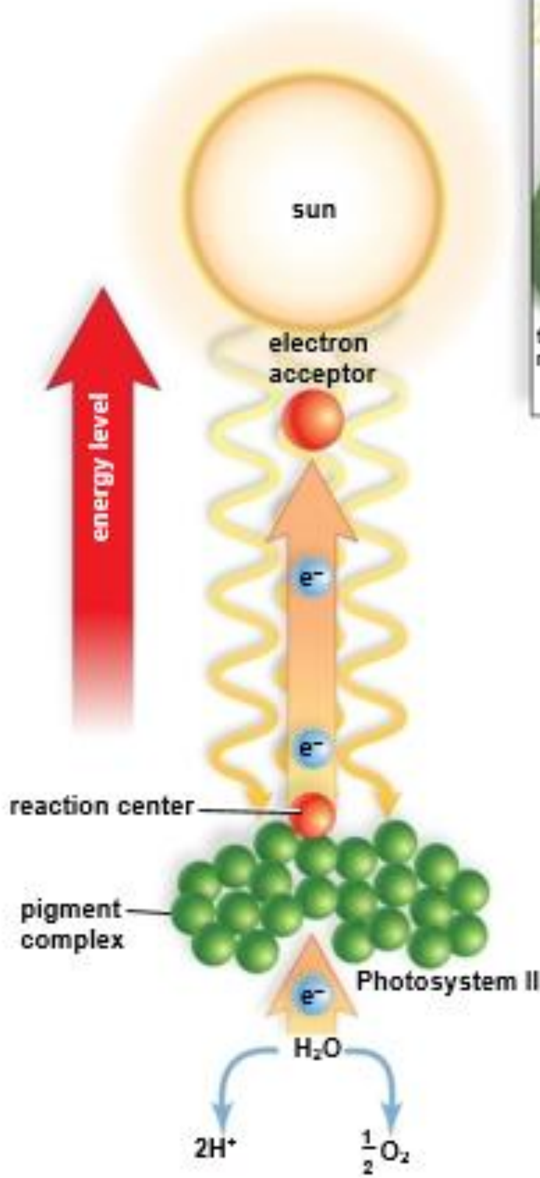
- Which comes first, photosystem I or photosystem II? Why?
- What happens in both of these photosystems?

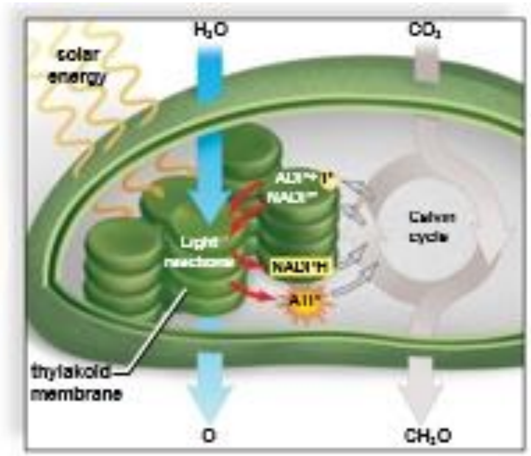
7-20

Noncyclic Electron Pathway (1)

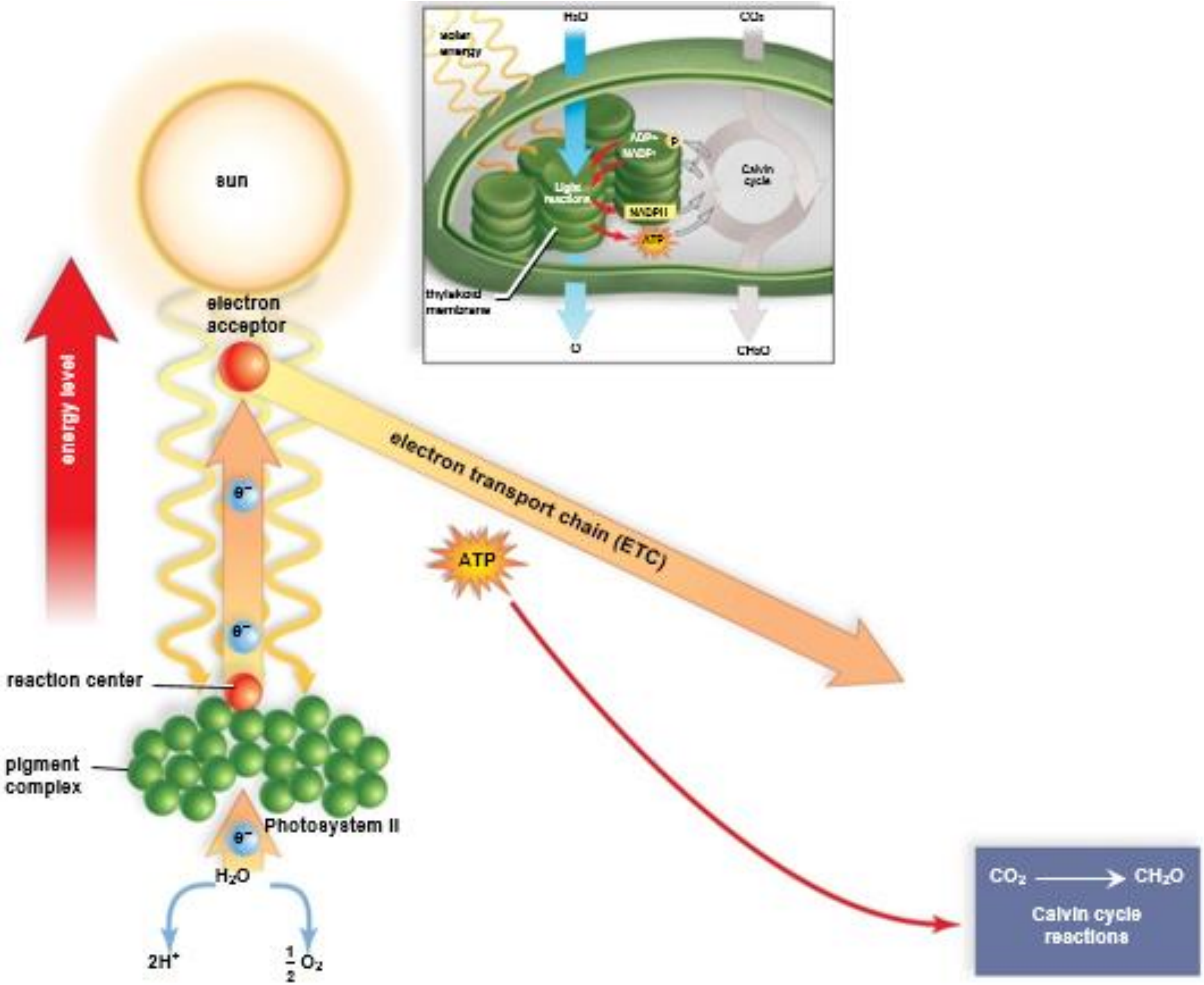


Noncyclic Electron Pathway (2)

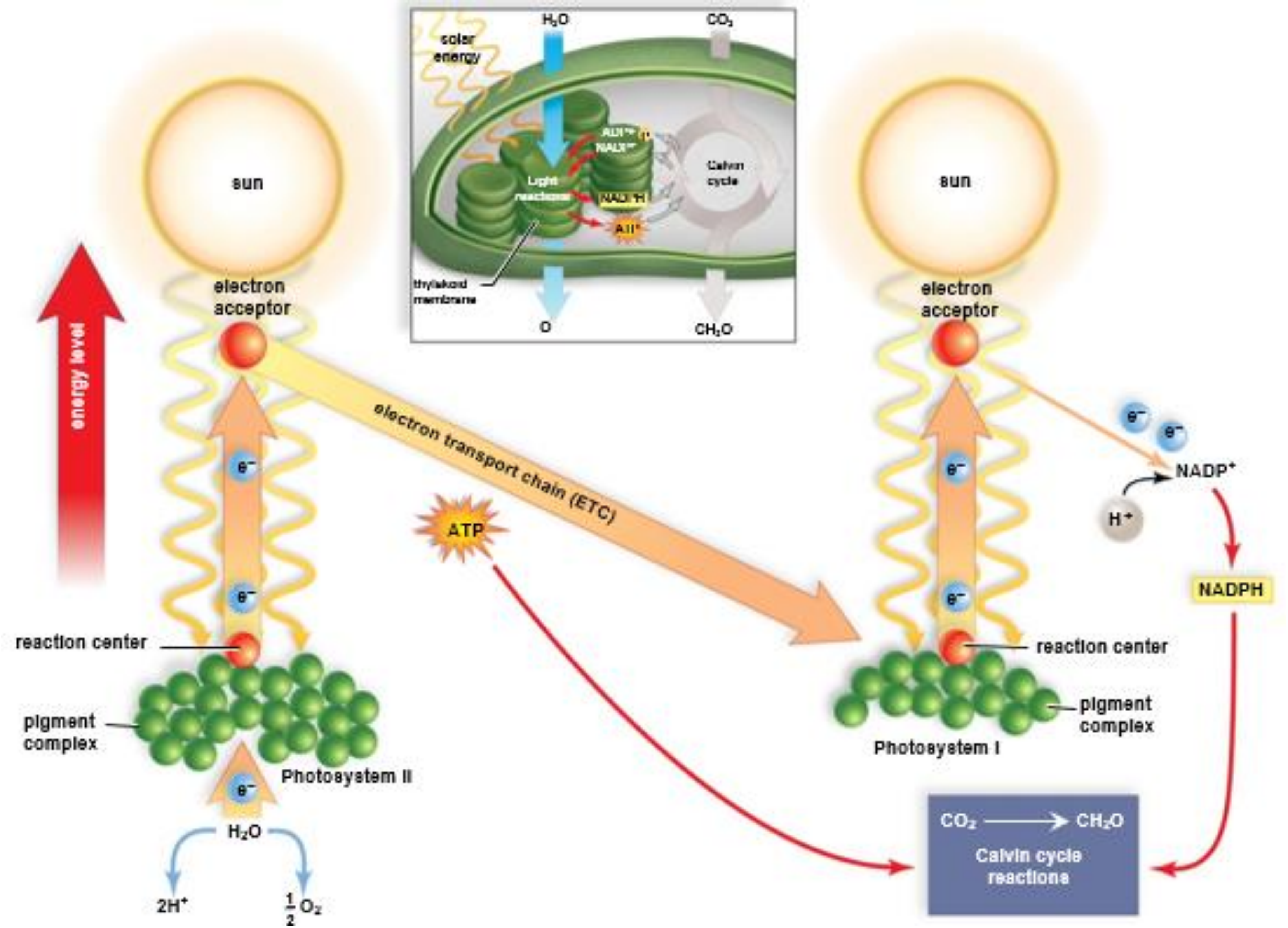




Noncyclic Electron Pathway (3)



Noncyclic Electron Pathway (4)



Jump to Noncyclic Electron Pathway (4) Long Description

Plants Convert Solar Energy (3)

PS II:

- Consists of a pigment complex and electron acceptors
- Receives electrons from the splitting of water
- Oxygen is released as a gas.

Electron transport chain:

- Consists of cytochrome complexes and plastoquinone
- Carries electrons between PS II and PS I
- Also pumps H^+ from the stroma into the thylakoid space

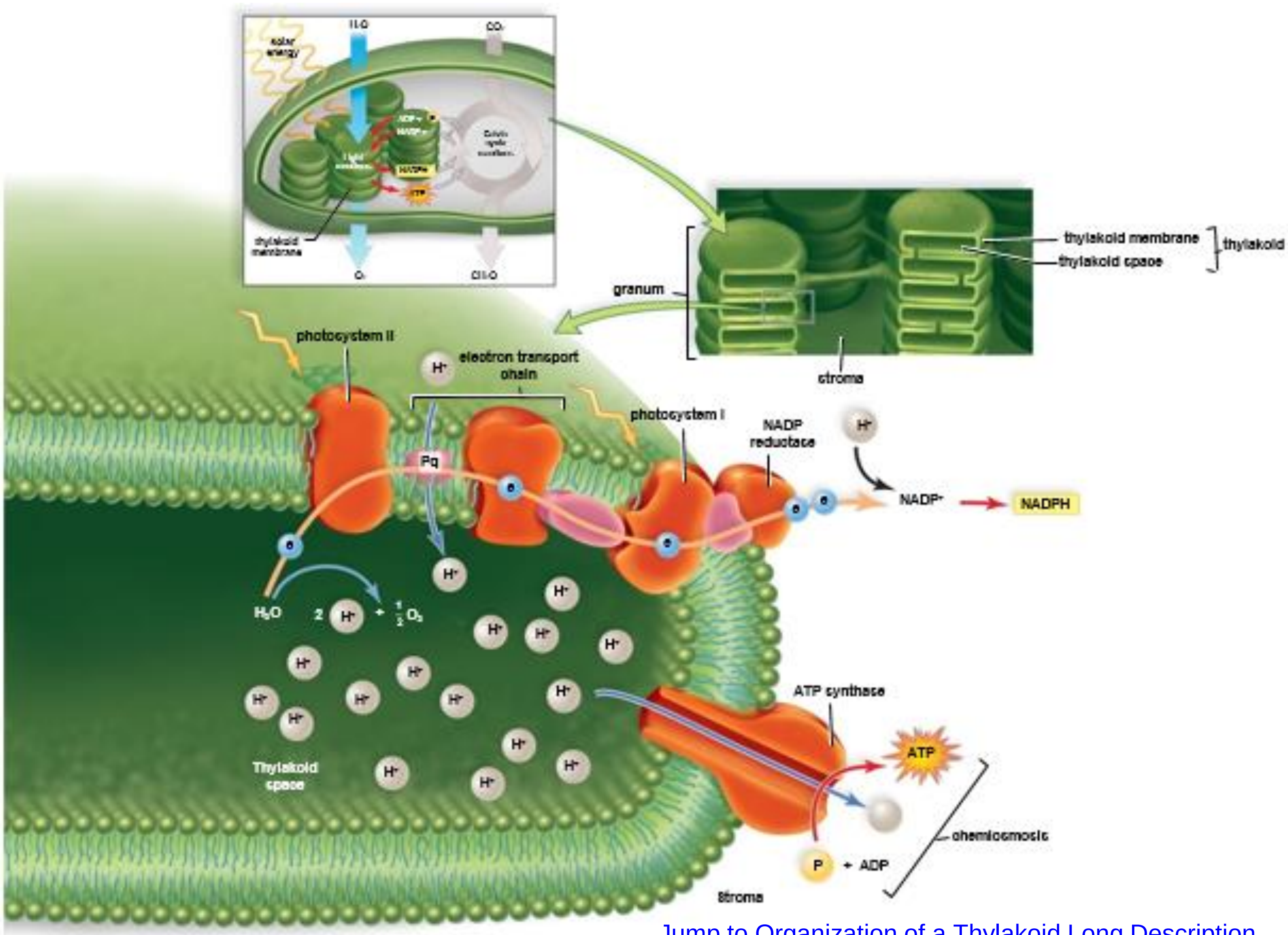
PS I:

- Has a pigment complex and electron acceptors
- Adjacent to the enzyme that reduces $NADP^+$ to NADPH

ATP synthase complex:

- Has a channel for H^+ flow
- H^+ flow through the channel drives ATP synthase to join ADP and P_i to each other.

Organization of a Thylakoid



Jump to Organization of a Thylakoid Long Description

Plants as Solar Energy Converters

The thylakoid space acts as a reservoir for hydrogen ions (H^+).

Each time water is oxidized, two H^+ remain in the thylakoid space.

Transfer of electrons in the electron transport chain yields energy.

- This energy is used to pump H^+ across the thylakoid membrane.
- Protons move from the stroma into the thylakoid space.

The flow of H^+ back across the thylakoid membrane energizes ATP synthase.

- ATP synthase enzymatically produces ATP from $ADP + P_i$.

This method of producing ATP is called **chemiosmosis**, because ATP production is tied to the establishment of an H^+ gradient.

Tropical Rain Forest Destruction and Climate Change (1)

Tropical rain forests can exist where:

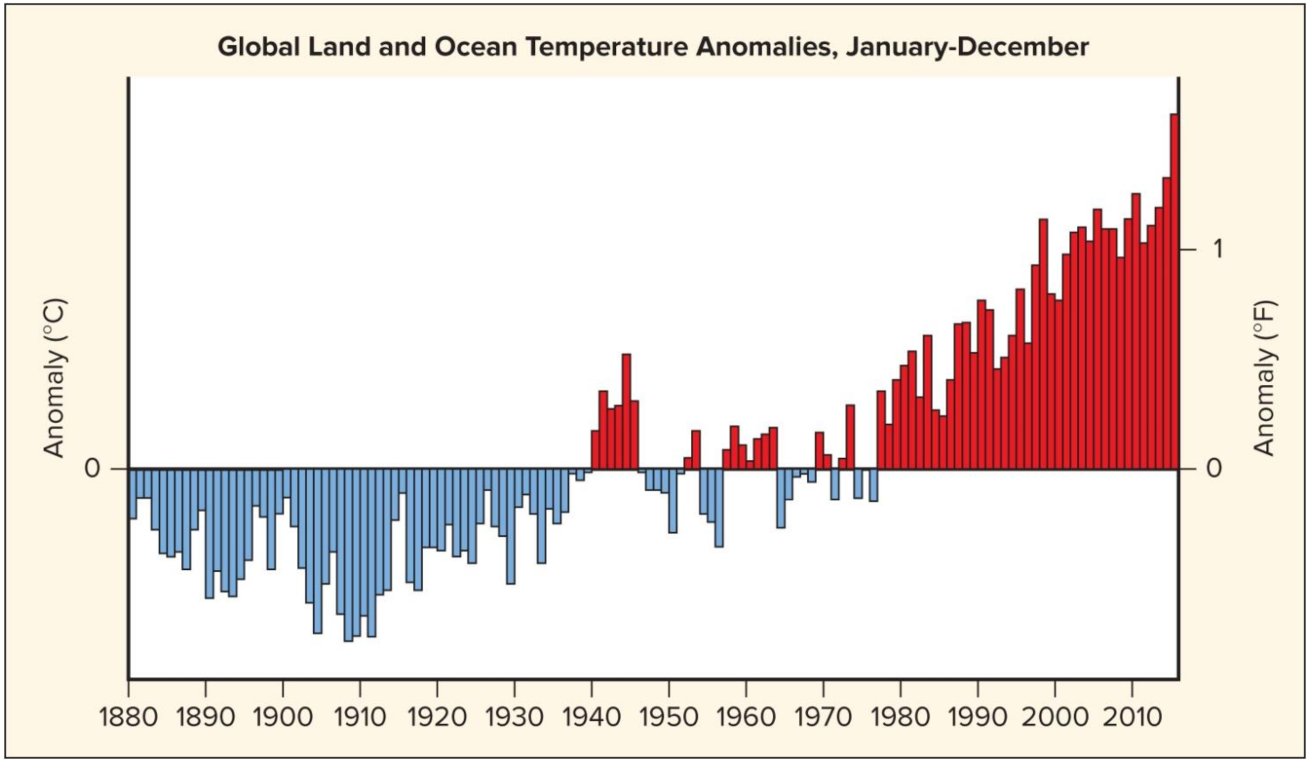
- Temperatures are above 26 degree Celsius
- Rainfall is heavy (100 to 200 centimeters) and regular.

Most tropical rain forest plants are woody; many vines and epiphytes; little or no undergrowth.

Tropical rain forests contribute greatly to CO_2 uptake, slowing global warming.

- Development has reduced them from 15% to 5% of the Earth's surface.
- Deforestation accounts for 10 to 20% of atmospheric CO_2, but also removes a CO_2 sink.
- The burning of fossil fuels adds CO_2 to the air.
- Increasing temperatures also reduce productivity.

Tropical Rain Forest Destruction and Climate Change (2)



Jump to Tropical Rain Forest Destruction and Climate Change (2) Long Description

7.4 Plants Fix Carbon Dioxide

A cyclical series of reactions

Utilizes atmospheric carbon dioxide to produce carbohydrates

Known as C_3 photosynthesis

Involves three stages:

- **Carbon dioxide fixation**
- Carbon dioxide reduction
- RuBP regeneration

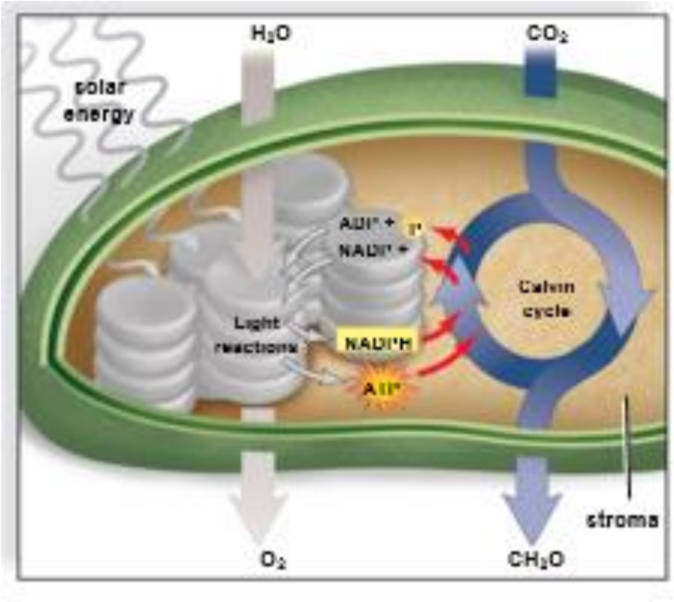
Plants as Carbon Dioxide Fixers

CO_2 is attached to 5-carbon **RuBP** by the enzyme RuBP carboxylase.

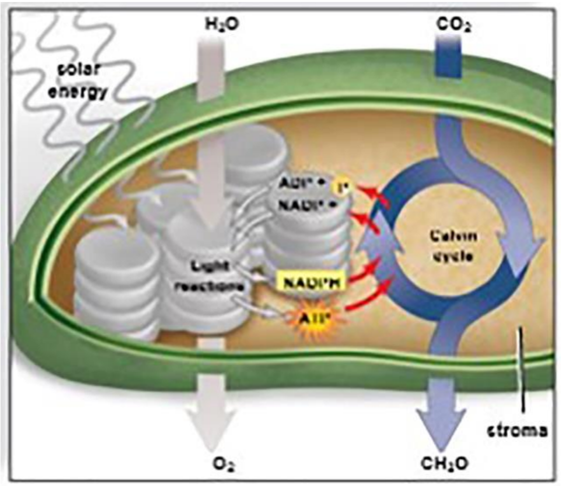
- Results in a 6-carbon molecule
- This splits into two 3-carbon molecules (3PG)
- Reaction is accelerated by RuBP carboxylase (Rubisco)

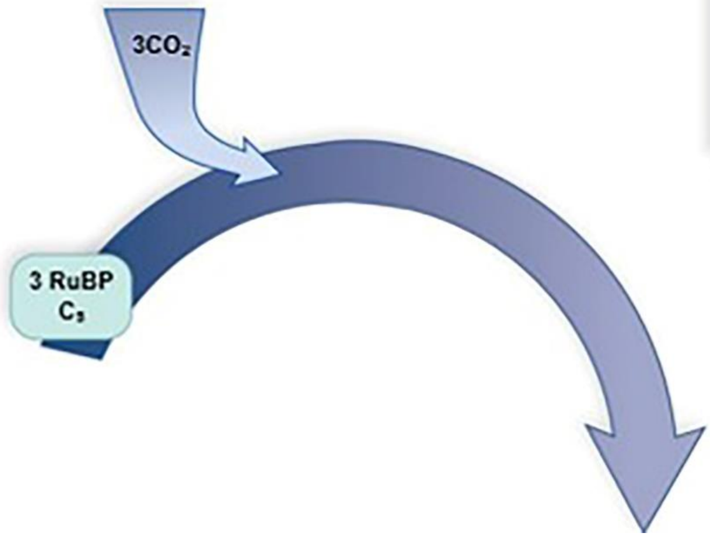
CO_2 is now "fixed" because it is part of a carbohydrate.

The Calvin Cycle Reactions (1)



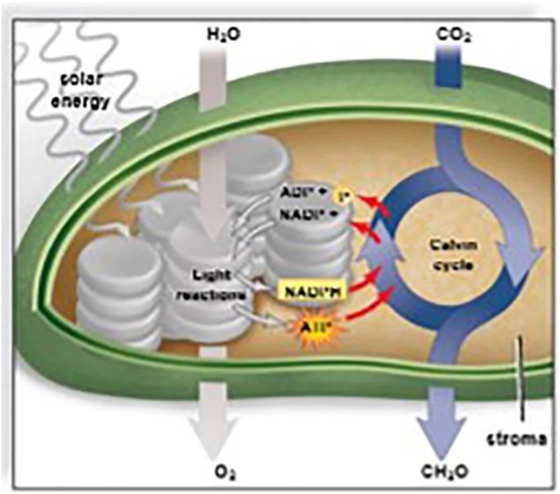
The Calvin Cycle Reactions (2)

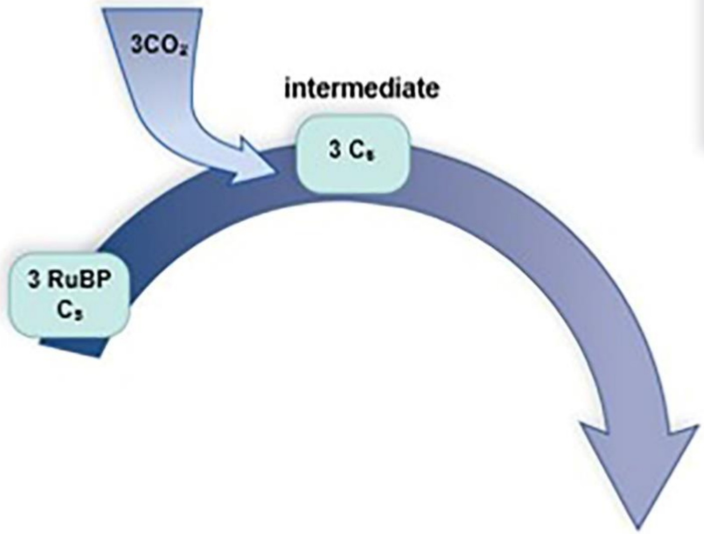




Metabolites of the Calvin Cycle	
RuBP	ribulose-1,5-bisphosphate
3PG	3-phosphoglycerate
BPG	1,3-bisphosphoglycerate
G3P	glyceraldehyde-3-phosphate

The Calvin Cycle Reactions (3)





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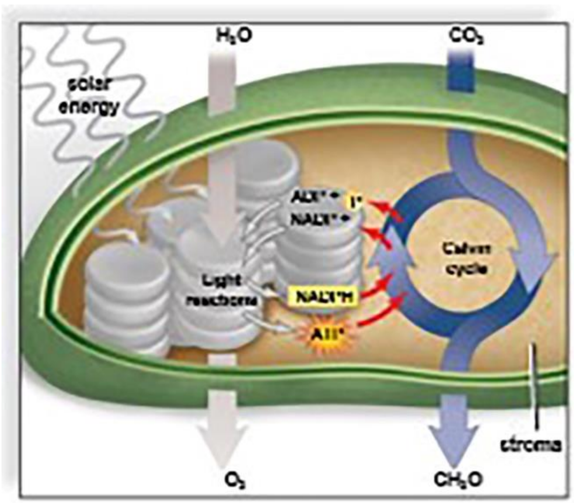
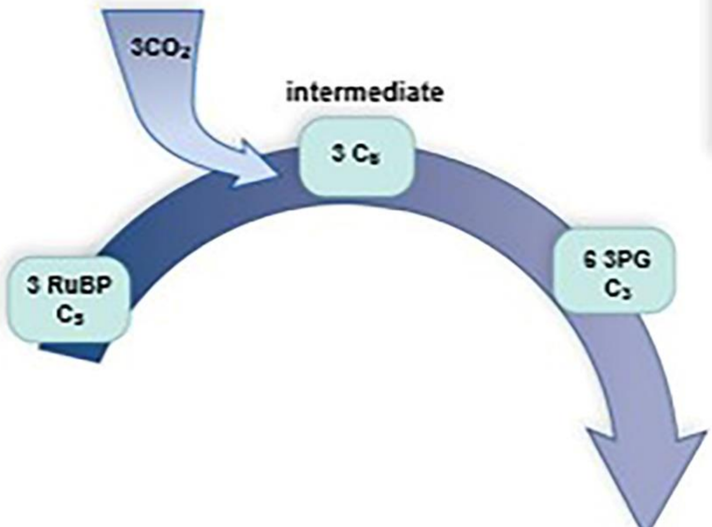
The Calvin Cycle Reactions (4)





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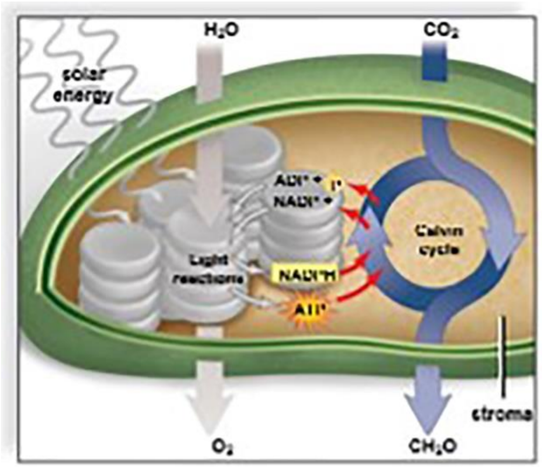
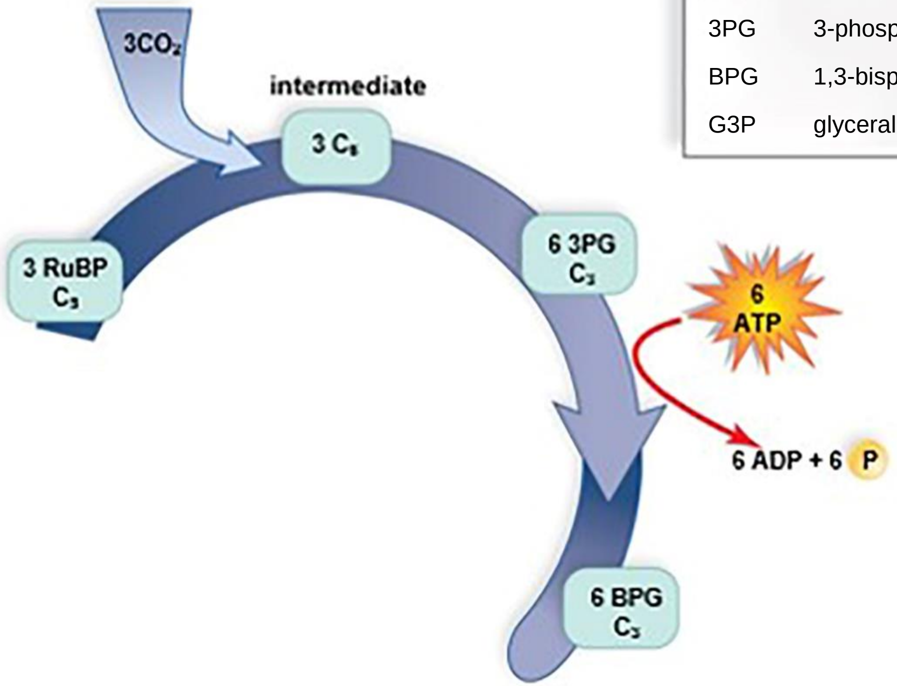
The Calvin Cycle Reactions (5)





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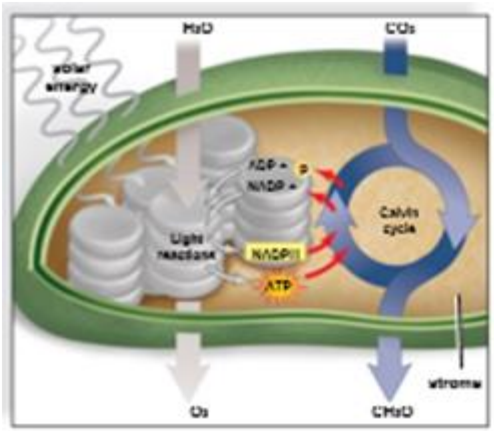
The Calvin Cycle Reactions (6)



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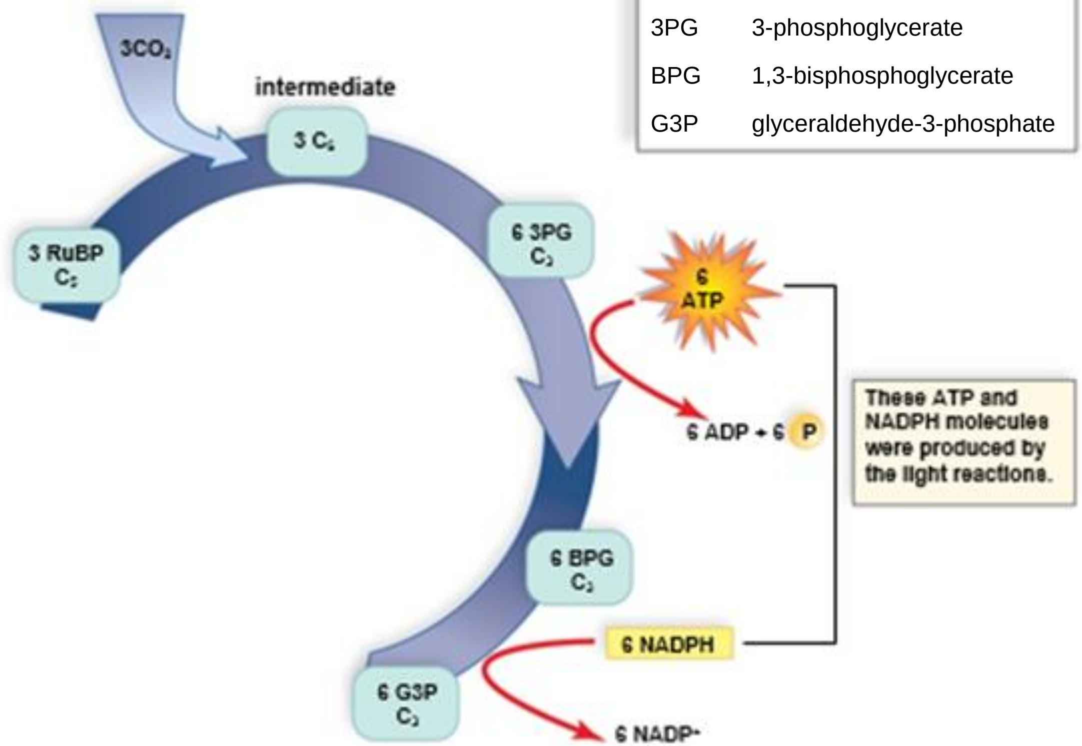
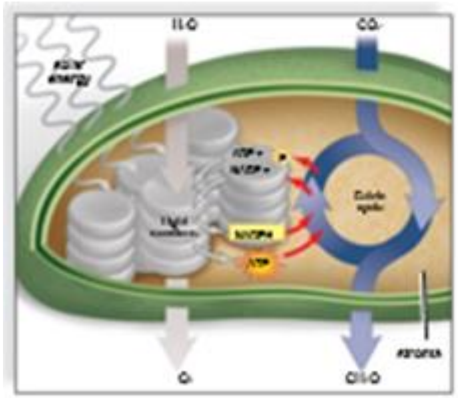


The Calvin Cycle Reactions (7)



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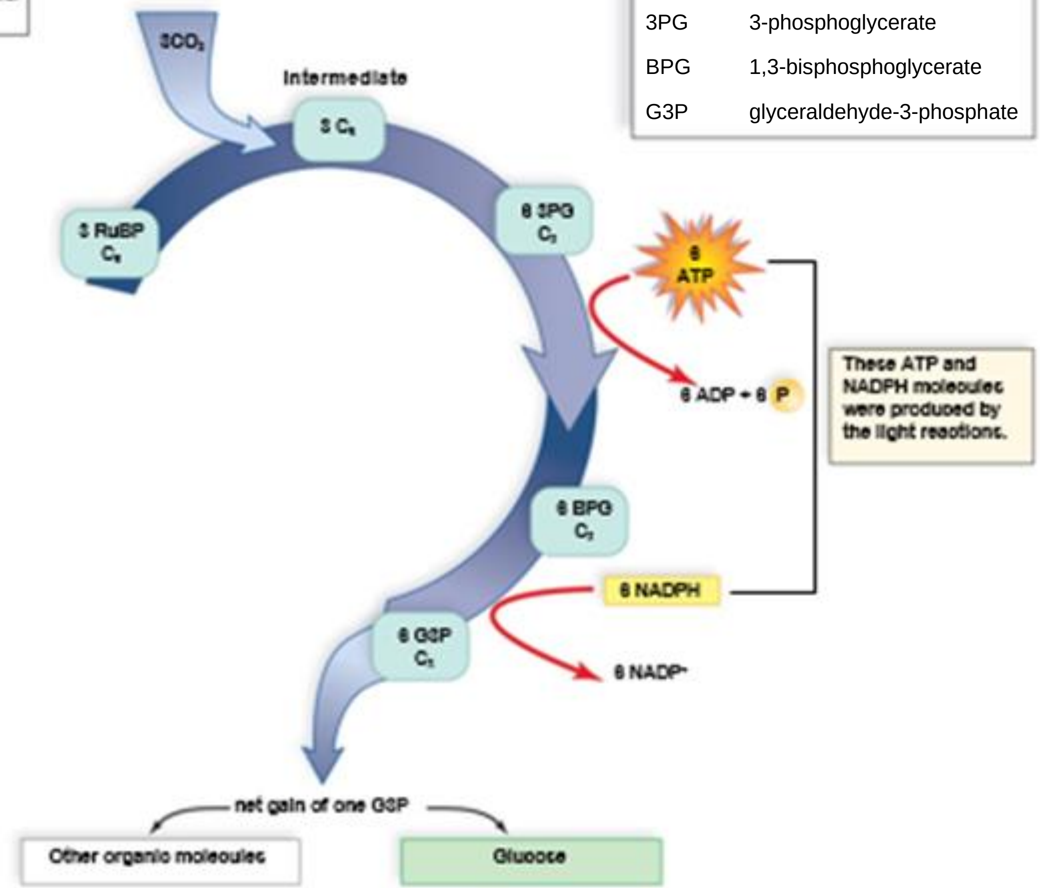
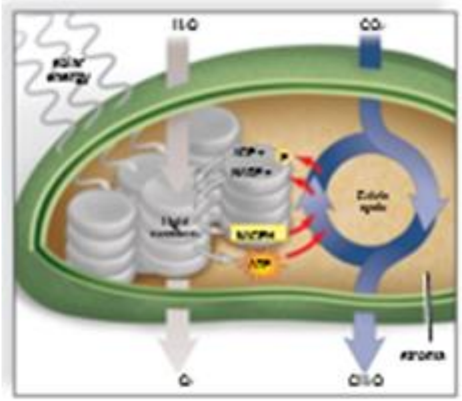


The Calvin Cycle Reactions (8)



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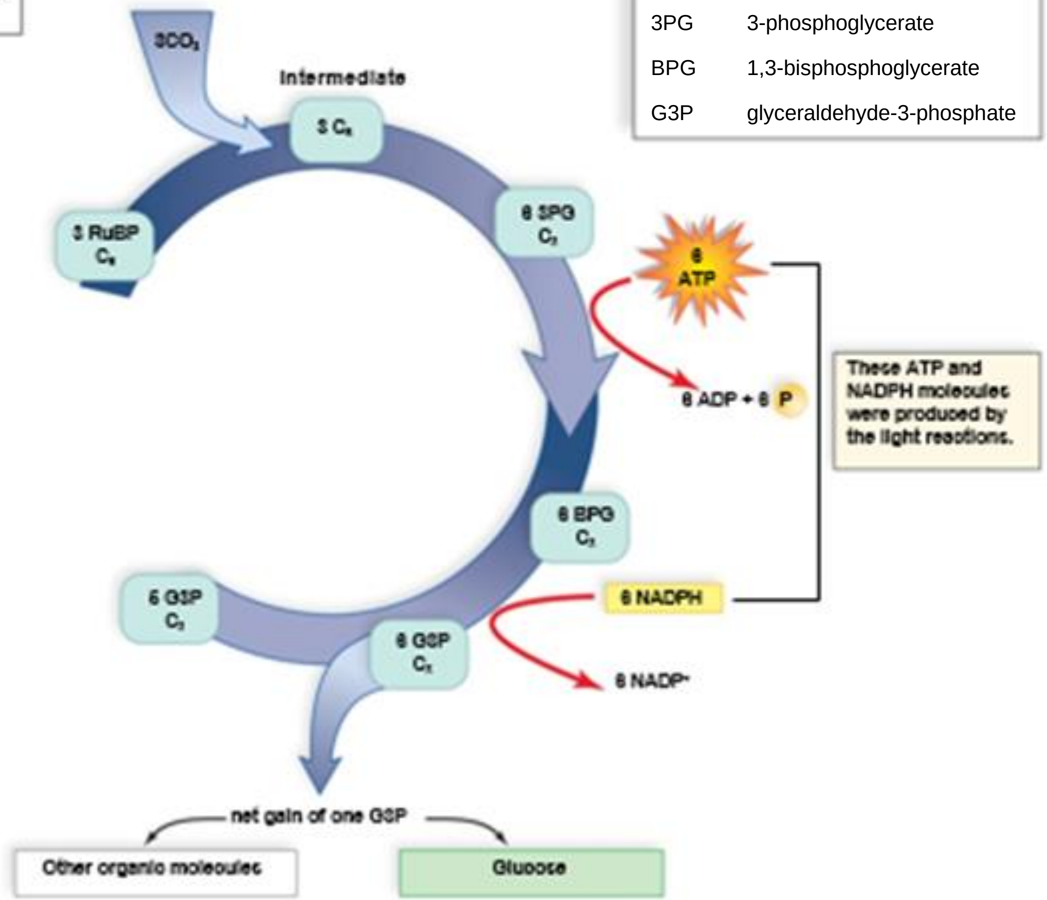
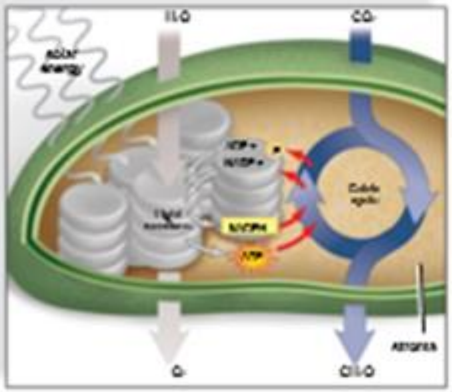


The Calvin Cycle Reactions (9)



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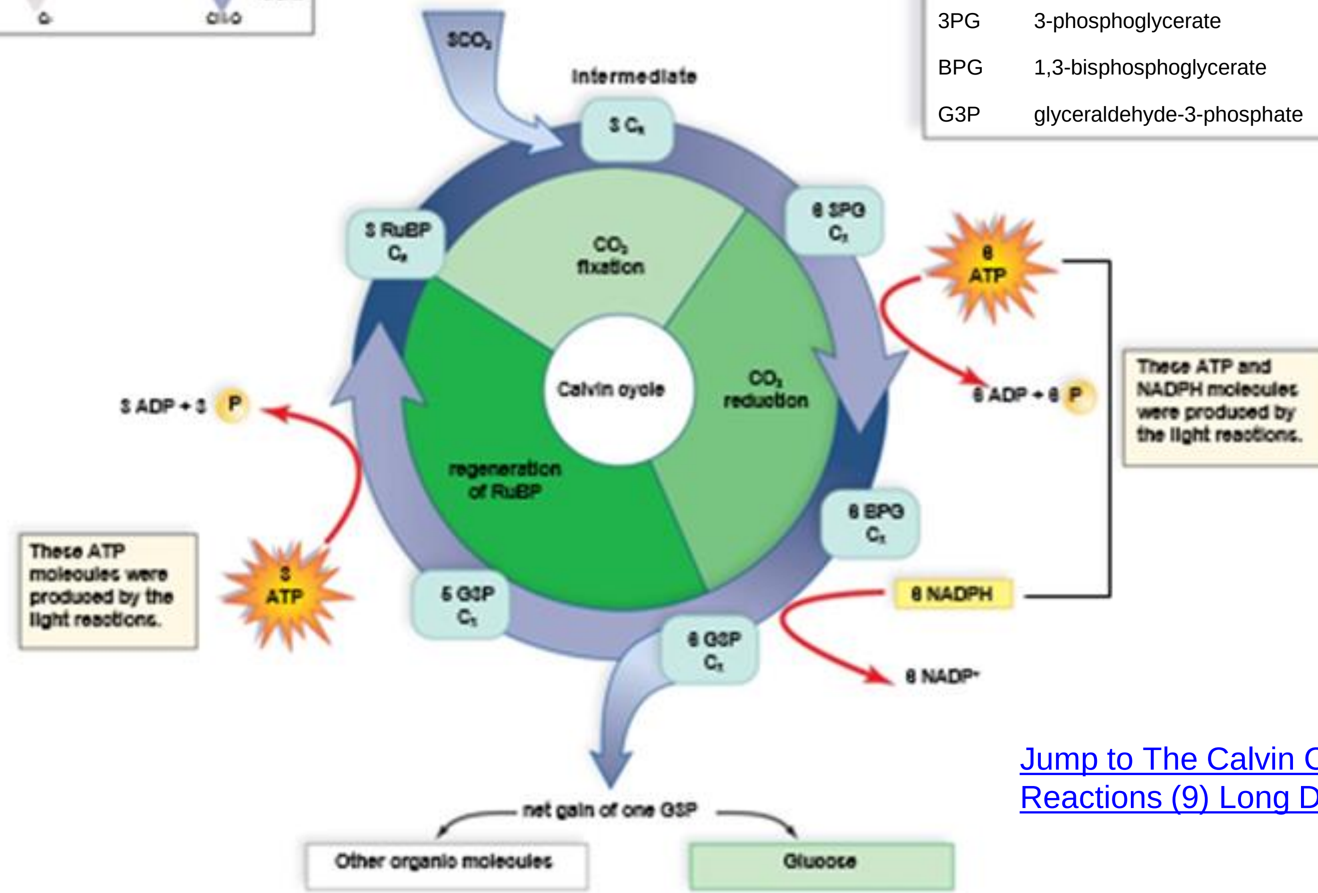


Jump to The Calvin Cycle Reactions (9) Long Description

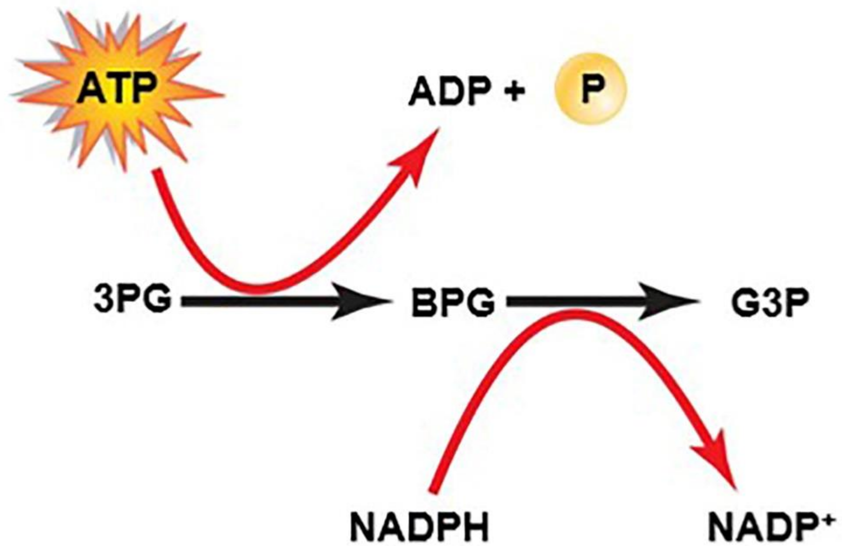
Plants Fix Carbon Dioxide (1)

3PG is reduced to BPG.

BPG is then reduced to G3P.

- Electrons and energy are required for this stage.
- This stage utilizes NADPH and some ATP produced in the light reactions.
  - G3P is reduced and chemically able to store more energy and form larger organic molecules such as glucose.

Reduction of Carbon Dioxide



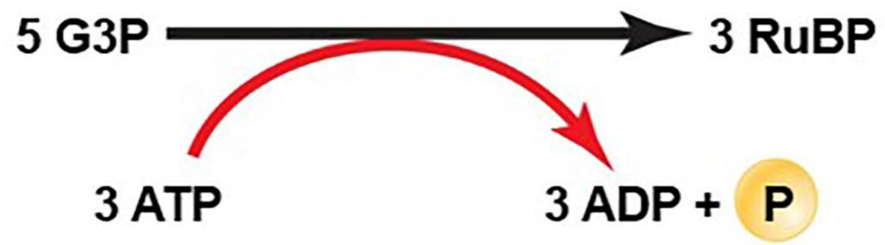
As 3PG becomes G3P, ATP becomes ADP + P and NADPH becomes $NADP^+$

Plants Fix Carbon Dioxide (2)

Regeneration of RuBP

- RuBP used in CO_2 fixation must be replaced.
- Every three turns of Calvin cycle:
  - Five G3P (a 3-carbon molecule) are used to remake three RuBP (a 5-carbon molecule).
  - $5 \times 3 = 3 \times 5$

Regeneration of RuBP



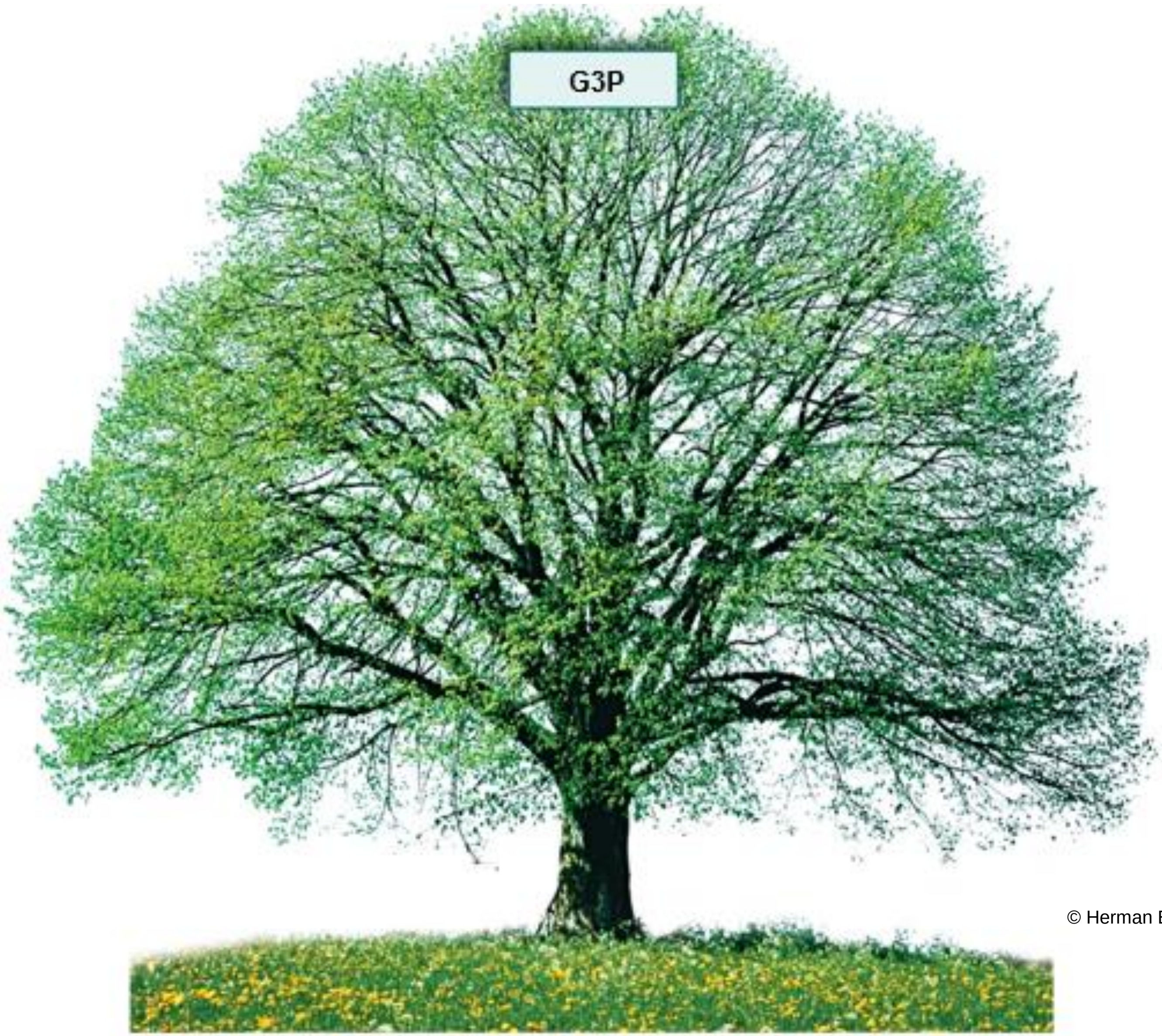
As five molecules of G3P become three molecules of RuBP, three molecules of ATP become three molecules of ADP +P .

Plants Fix Carbon Dioxide (3)

Importance of the Calvin cycle:

- G3P (glyceraldehyde-3-phosphate) can be converted to many other molecules.
- The hydrocarbon skeleton of G3P can form:
  - Fatty acids and glycerol to make plant oils
  - Glucose phosphate (simple sugar)
  - Fructose (which with glucose = sucrose)
  - Starch and cellulose
  - Amino acids

Fate of G3P (1)



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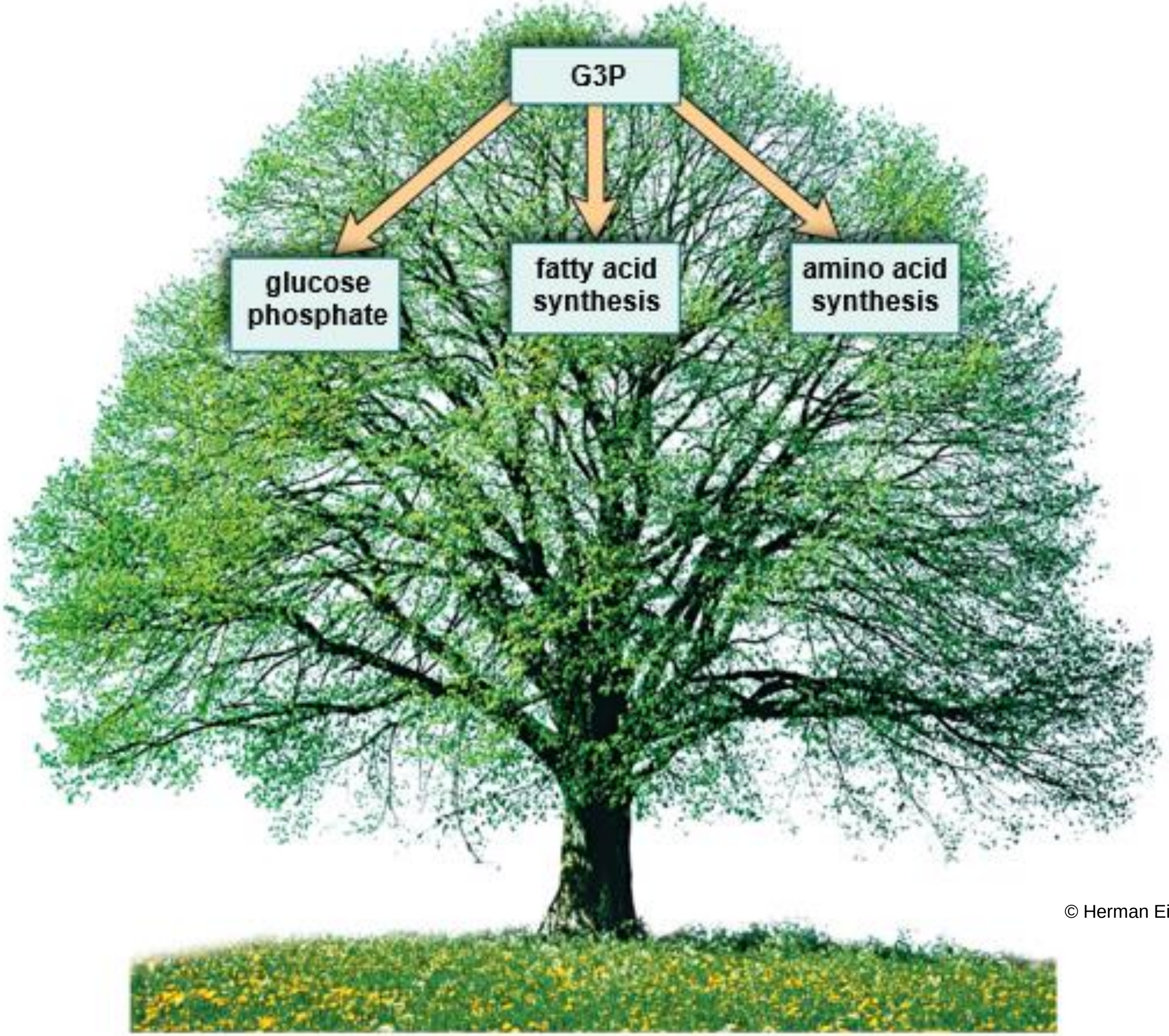
Fate of G3P (2)



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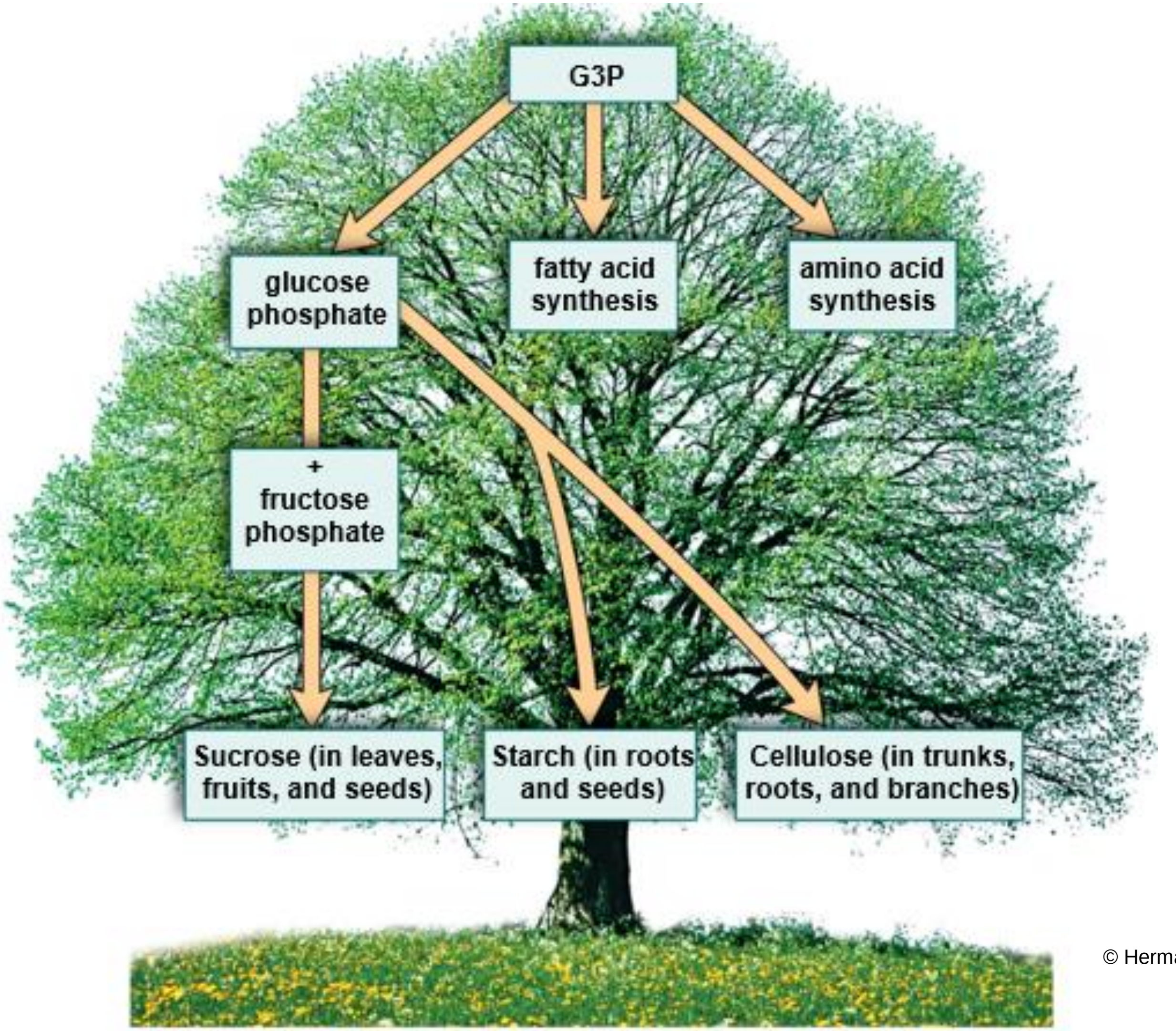
Fate of G3P (3)



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Jump to Fate of G3P (3) Long Description

7.5 Other Types of Photosynthesis

The majority of plants carry out C_3 photosynthesis.

- These use RuBP carboxylase to fix CO_2 to RuBP in the mesophyll cells.

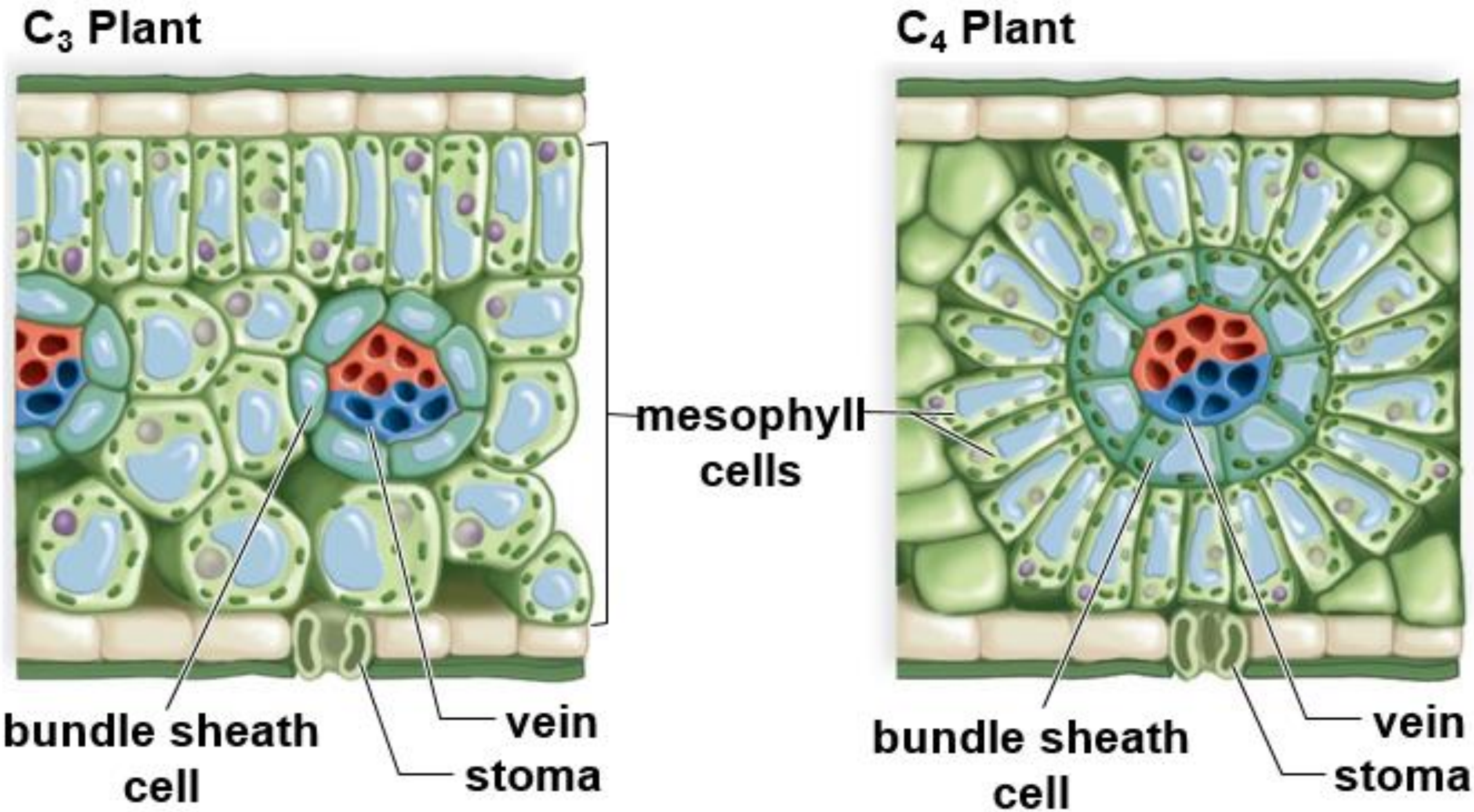
In hot, dry climates

- Stomata must close to avoid wilting.
- CO_2 decreases and O_2 increases.
- O_2 starts combining with RuBP, leading to the production of CO_2.
- This is called photorespiration.

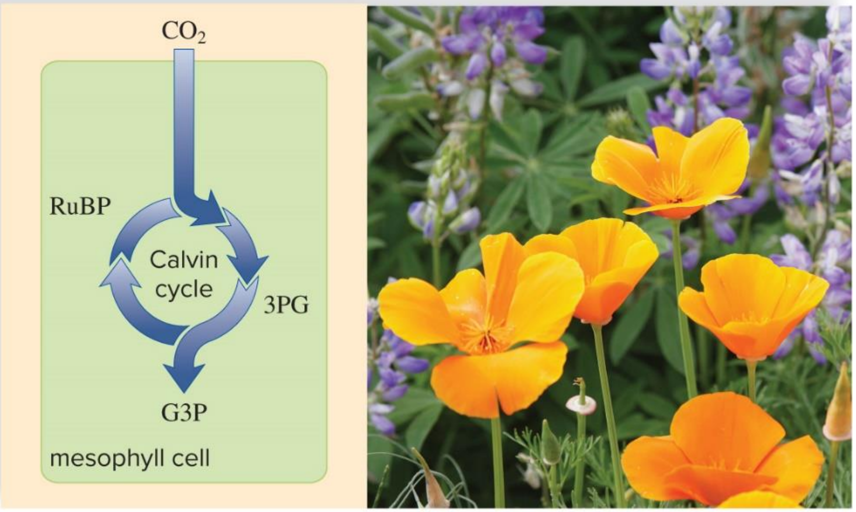
C_4 plants solve the problem of photorespiration.

- Fix CO_2 to PEP (a C_3 molecule)
- The result is oxaloacetate, a C_4 molecule
- In hot and dry climates
  - C_4 **plants** avoid photorespiration.
  - Net productivity is about 2 to 3 times greater than C_3 **plants**.
- In cool, moist environments, C_4 plants can't compete with C_3 plants.

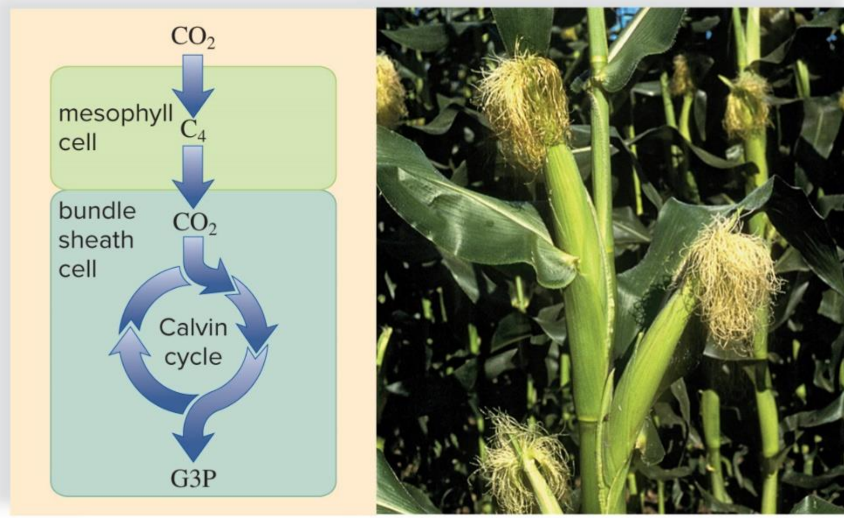
Chloroplast Distribution in C_4 versus C_3 Plants



CO_2 Fixation in C_3 and C_4 Plants



(photo): ©Don Paulson Photography/Purestock/Superstock RF



(photo): Source: USDA/Doug Wilson, photographer

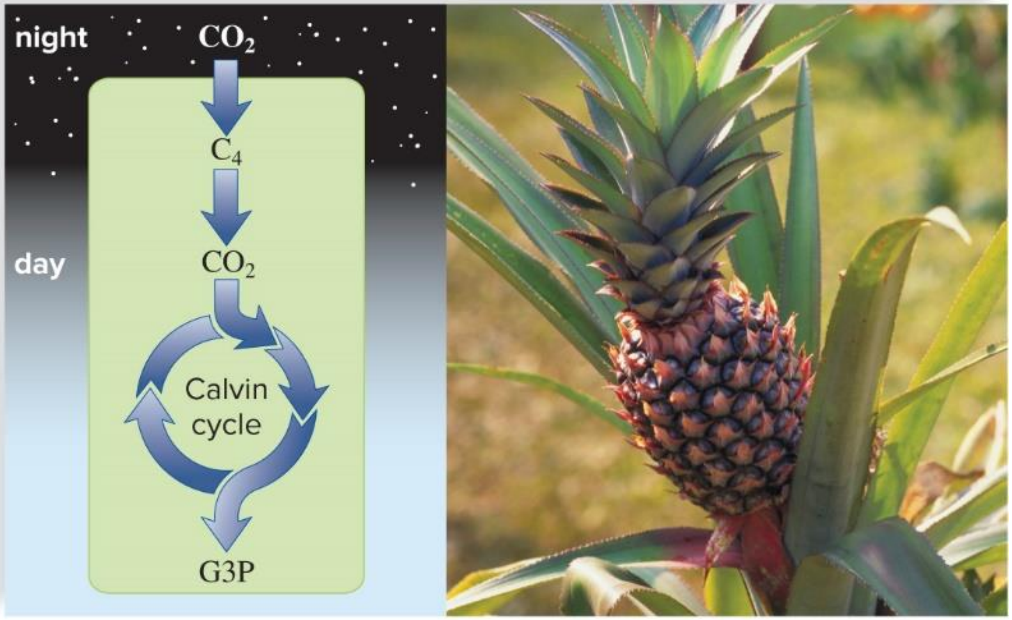
Jump to CO_2 Fixation in C_3 and C_4 Plants Long Description

Other Types of Photosynthesis

CAM Photosynthesis

- Crassulacean-acid metabolism
- CAM plants partition carbon fixation by time.
  - During the night
    - CAM plants fix CO_2
    - Form C_4 molecules, which are
    - Stored in large vacuoles
  - During daylight
    - NADPH and ATP are available
    - Stomata are closed for water conservation
    - C_4 molecules release CO_2 to Calvin cycle

CO_2 Fixation in a CAM Plant



CO_2 fixation in a CAM plant, pineapple, *Ananas comosus*

(photo): ©Pixtal/age fotostock RF

Jump to CO_2 Fixation in a CAM Plant Long Description

Photosynthesis and Adaptation to the Environment

The different methods of photosynthesis each have advantages and disadvantages.

- Depends on the climate

C_4 plants most adapted to:

- High light intensities
- High temperatures
- Limited rainfall

C_3 plants better adapted to:

- Cold (below 25 degree Celsius)
- High moisture

CAM plants are better adapted to extreme aridity.

- CAM occurs in 23 families of flowering plants.
- They are also found among nonflowering plants.