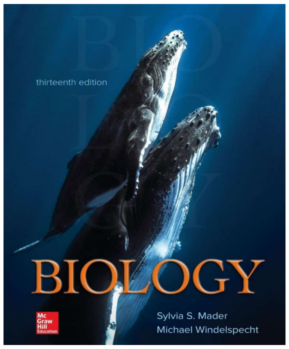
Photosynthesis



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.

7-1

Outline

7-2

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.

7-3

Photosynthesis

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.

7-4

Photosynthetic Organisms (1)

Photosynthesis takes place in the green portions of plants.

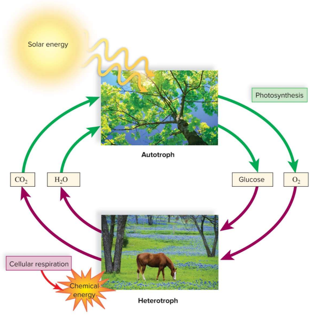
- The leaf of the flowering plant contains mesophyll tissue.
- Cells containing **chloroplasts** are specialized to carry out photosynthesis.

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).

7-5

Photosynthetic Organisms (2)

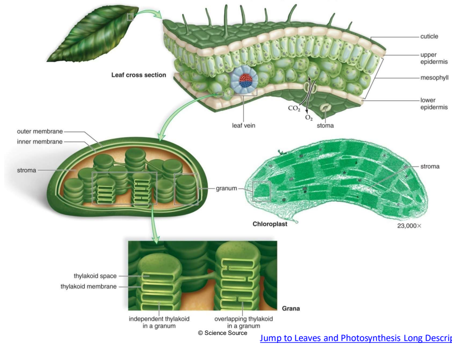


(photos): (autotroph): ©Design Pics/Don Hammond RF; (heterotroph): ©Jeff R. Clow/Getty RF

7-6

Photosynthesis

Leaves and Photosynthesis



© Science Source

Jump to Leaves and Photosynthesis Long Description 7-7

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.

7-8

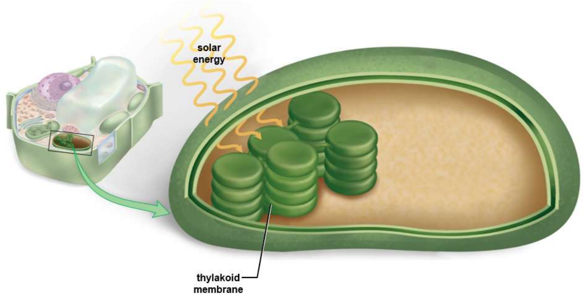
Photosynthesis Releases Oxygen

© Nigel Cattlin/Science Source

Jump to Photosynthesis Releases Oxygen Long Description 7-9

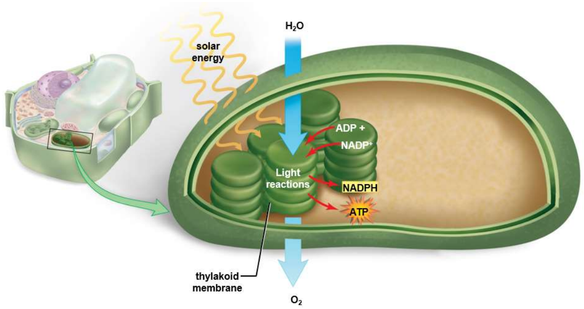
Photosynthesis

Overview of Photosynthesis (1)



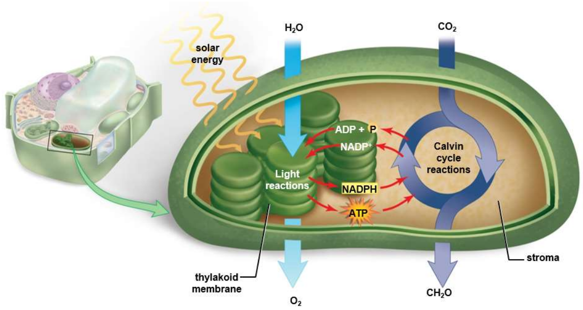
7-10

Overview of Photosynthesis (2)



7-11

Overview of Photosynthesis (3)



Jump to Overview of Photosynthesis (3) Long Description 7-12

Photosynthesis

7.3 Plants Convert Solar Energy

Pigments and photosystems:

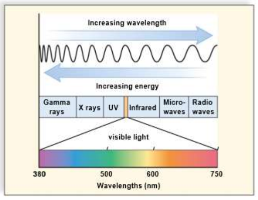
- Chemicals that absorb certain wavelengths of light are pigments.
- Wavelengths that are not absorbed by pigments are reflected or transmitted.

Absorption spectrum

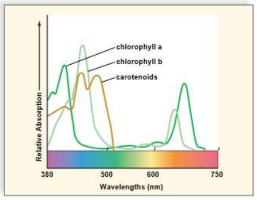
- Pigments found in chlorophyll absorb various portions of visible light.
- An absorption spectrum is a graph showing relative absorption of the various colors of the rainbow.
- Chlorophyll is green because it absorbs much of the reds and blues of white light and reflects green light.
  - Carotenoids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

7-13

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

7-14

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.

7-15

Photosynthesis

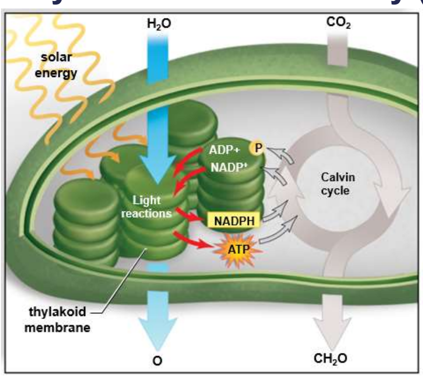
Plants Convert Solar Energy (2)

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

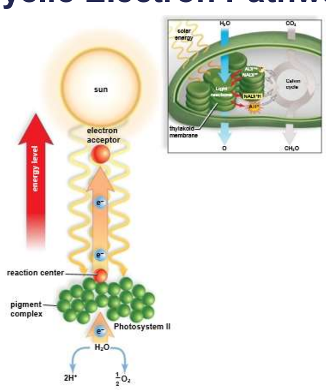
7-16

Noncyclic Electron Pathway (1)



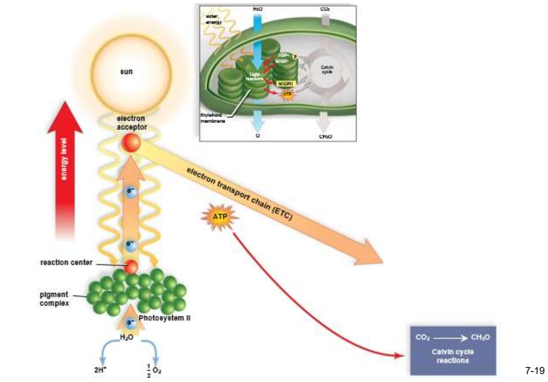
7-17

Noncyclic Electron Pathway (2)



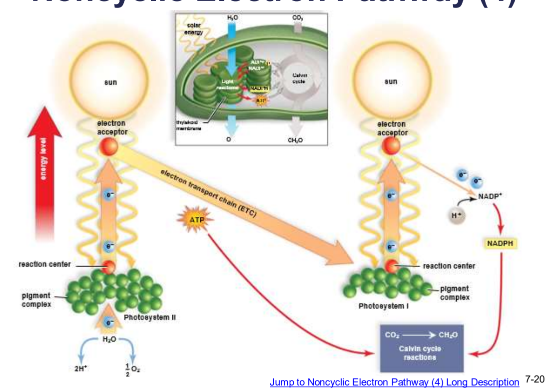
7-18

Noncyclic Electron Pathway (3)



7-19

Noncyclic Electron Pathway (4)



Jump to Noncyclic Electron Pathway (4) Long Description 7-20

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

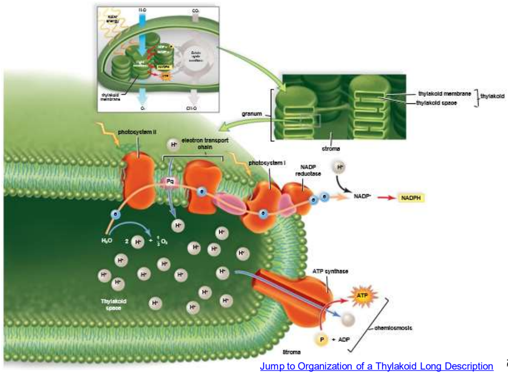
ATP synthase complex:

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

7-21

Photosynthesis

Organization of a Thylakoid



Jump to Organization of a Thylakoid Long Description

7-22

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.

7-23

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.

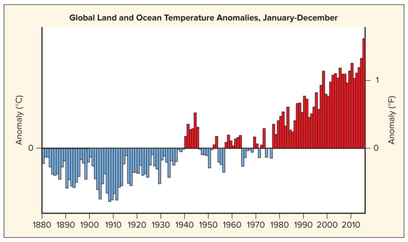
Tropical rain forests contribute greatly to CO_2 uptake, slowing global warming.

- 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.

7-24

Photosynthesis

Tropical Rain Forest Destruction and Climate Change (2)



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

7-25

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

7-26

Plants as Carbon Dioxide Fixers

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

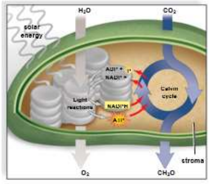
- Results in a 6-carbon molecule
- This splits into two 3-carbon molecules (3PG)
- Reaction is accelerated by RuBP carboxylase (Rubisco)

CO_2 is now “fixed” because it is part of a carbohydrate.

7-27

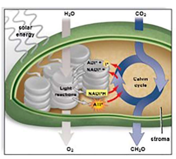
Photosynthesis

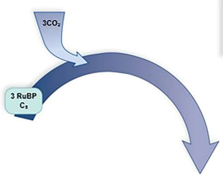
The Calvin Cycle Reactions (1)



7-28

The Calvin Cycle Reactions (2)

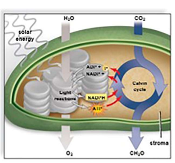


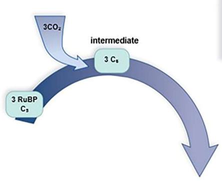


Metabolites of the Calvin Cycle	
RuBP	ribulose-1,5-bisphosphate
3PG	3-phosphoglycerate
BPG	1,3-bisphosphoglycerate
G3P	glyceraldehyde-3-phosphate

7-29

The Calvin Cycle Reactions (3)



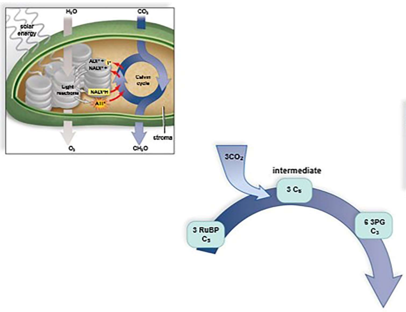


Metabolites of the Calvin Cycle	
RuBP	ribulose-1,5-bisphosphate
3PG	3-phosphoglycerate
BPG	1,3-bisphosphoglycerate
G3P	glyceraldehyde-3-phosphate

7-30

Photosynthesis

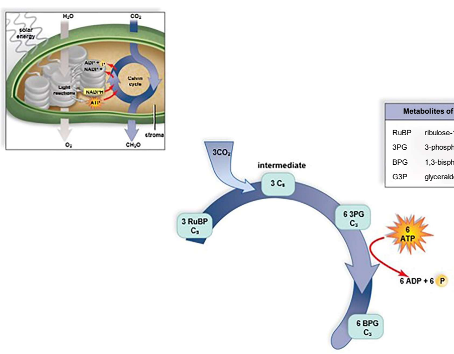
The Calvin Cycle Reactions (4)



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

7-31

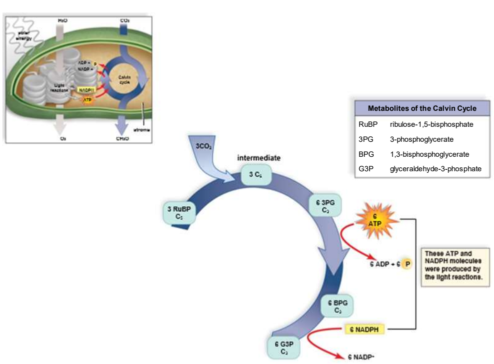
The Calvin Cycle Reactions (5)



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

7-32

The Calvin Cycle Reactions (6)

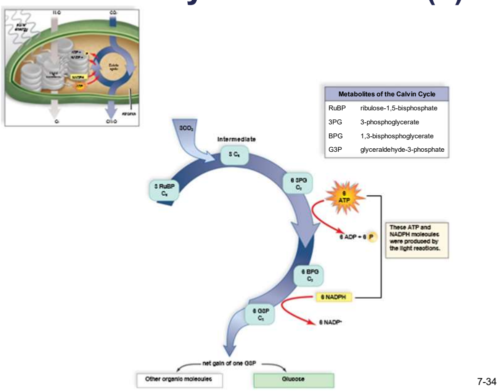


Metabolites of the Calvin Cycle	
RuBP	ribulose-1,5-bisphosphate
3PG	3-phosphoglycerate
BPG	1,3-bisphosphoglycerate
G3P	glyceraldehyde-3-phosphate

7-33

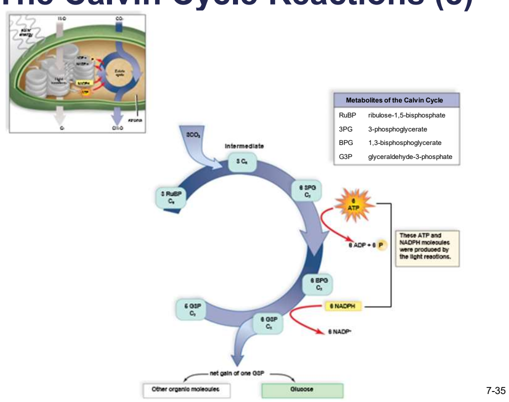
Photosynthesis

The Calvin Cycle Reactions (7)



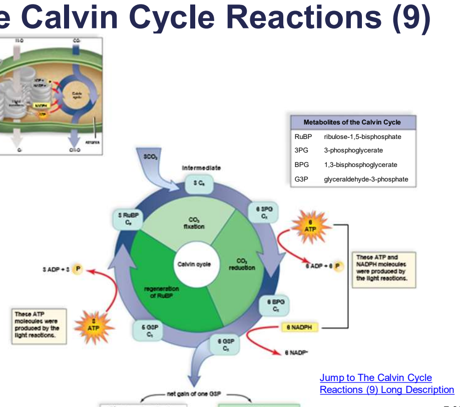
7-34

The Calvin Cycle Reactions (8)



7-35

The Calvin Cycle Reactions (9)



Jump to The Calvin Cycle Reactions (9) Long Description

7-36

Photosynthesis

Plants Fix Carbon Dioxide (1)

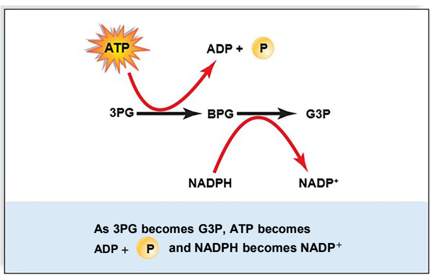
3PG is reduced to BPG.

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.

7-37

Reduction of Carbon Dioxide



7-38

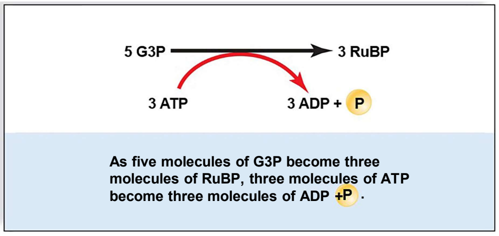
Plants Fix Carbon Dioxide (2)

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).
  - $5 \times 3 = 3 \times 5$

7-39

Regeneration of RuBP



7-40

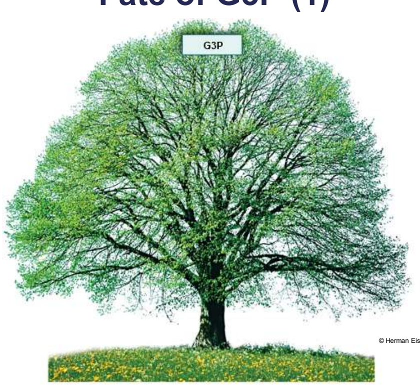
Plants Fix Carbon Dioxide (3)

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

7-41

Fate of G3P (1)



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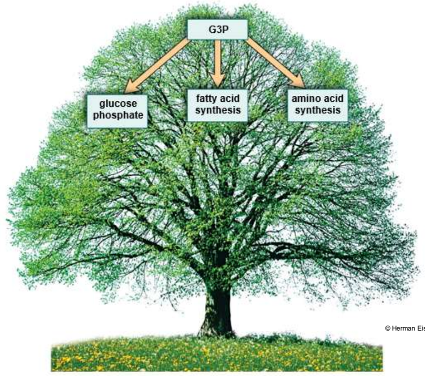
7-42

Photosynthesis

Fate of G3P (2)



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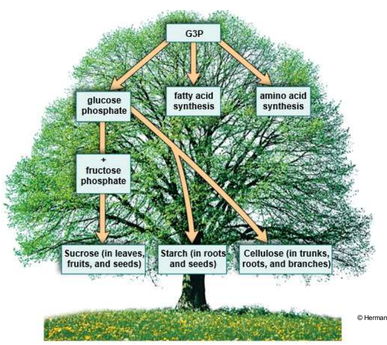
7-43

Fate of G3P (3)



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Jump to Fate of G3P (3) Long Description

7-44

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

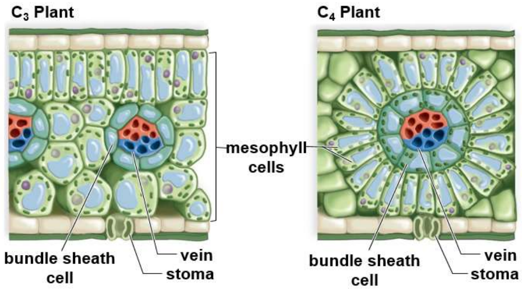
- Stomata must close to avoid wilting.
- CO_2 decreases and O_2 increases.
- O_2 starts combining with RuBP, leading to the production of CO_2.
- This is called photorespiration.

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.

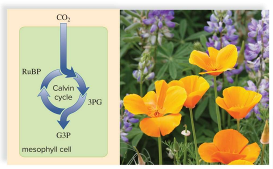
7-45

Chloroplast Distribution in C_4 versus C_3 Plants

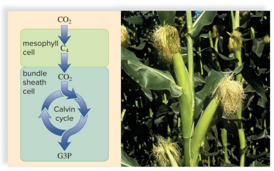


7-46

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 7-47

Other Types of Photosynthesis

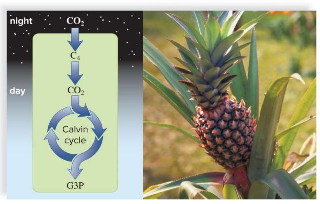
CAM Photosynthesis

- 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

7-48

Photosynthesis

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.