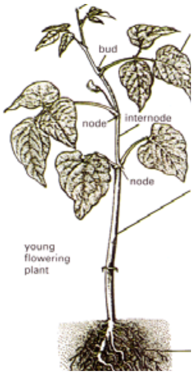
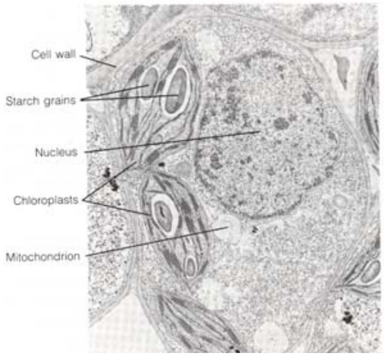




Lecture 17 Oct 10, 2005
Photosynthesis II. Calvin Cycle

Lecture Outline

1. The Calvin Cycle fixes carbon
   makes reduced carbon compounds
2. Reactions of the Calvin Cycle – anabolic pathway
   input of NADPH + H^+, input of ATP
3. Regulation of the Calvin Cycle
4. The problem with oxygen – Photorespiration
5. Tricks some plants use to limit photorespiration
   - C4 anatomy, C4 metabolism – division of labor
   - CAM plants, the difference is night and day

DARK REACTIONS
energy utilization

The Calvin Cycle

The purpose of the Carbon-fixation (Calvin Cycle) Reactions

CO_2 + NADPH + H^+ + ATP

↓

$C_6H_{12}O_6$ + $NADP^+$ + ADP + P_i

carbohydrate

Note: synthesis of carbohydrate from CO_2 is favorable only because coupled to very favorable reactions

NADPH to $NADP^+$

and

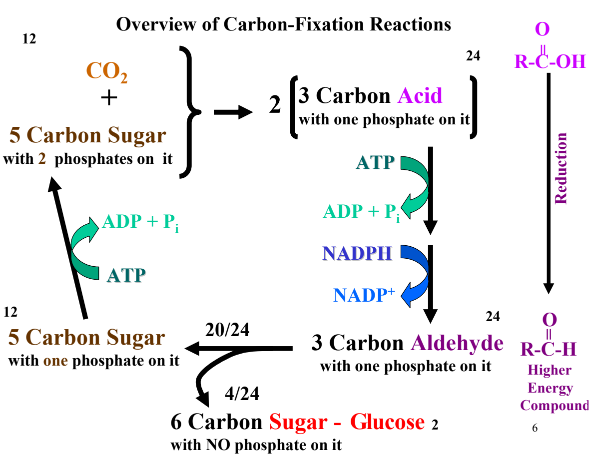
ATP to ADP + P_i

energy released is greater than it costs to make carbohydrate

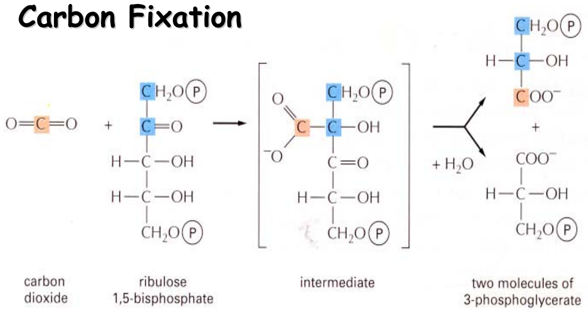
The Calvin cycle has three phases

- Carbon fixation
- Reduction (energy input, reducing equiv input)
- Regeneration of the CO_2 acceptor (energy input – "priming step")

Overview of Carbon-Fixation Reactions



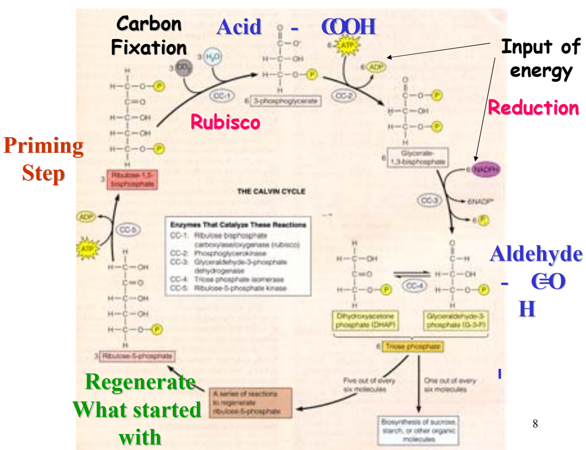
Carbon Fixation



Carried out by the enzyme "rubisco"
(ribulose 1,5 bisphosphate carboxylase oxygenase)

Do need to know this enzyme
Key regulatory enzyme

7



8

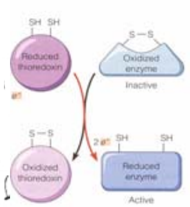
Regulation of Rubisco
1st Enzyme in Calvin Cycle

Substrate/Product availability

Allosterically regulated by NADPH and ATP

Very Narrow pH optimum
pH 8 or above, inactive at 7

Enzyme must be in
reduced form



9

Integration of Light-Dependent and Light-Independent Reactions

They generally occur AT THE SAME TIME

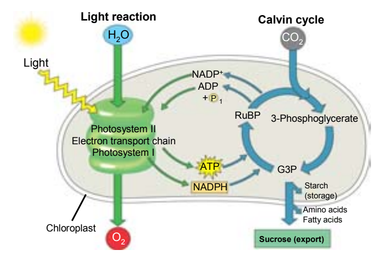


Figure 10.21

PhotoRespiration- "the OXYGEN PROBLEM"

Oxygen is a competing substrate for the 1st enzyme in the C_3 cycle (Rubisco)

CO_2 + 5 Carbon Sugar with 2 phosphates on it → 3 Carbon Acid with one phosphate on it + 3 Carbon Acid with one phosphate on it

Net increase in material make glucose with "extra"

O_2 + 5 Carbon Sugar with 2 phosphates on it → <u>2</u> Carbon Acid with one phosphate on it + 3 Carbon Acid with one phosphate on it

Energy Wasted With NO synthesis of glucose

Some Plants Deal with this problem by a

DIVISION OF LABOR BETWEEN CELLS

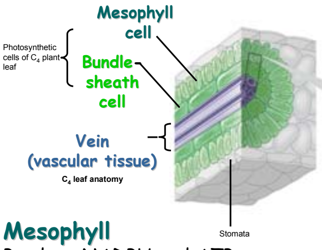
C_4 Plants

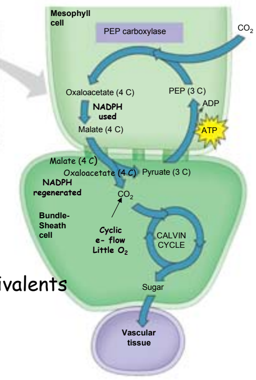
Mesophyll cells perform "usual" noncyclic Light-Dependent Reactions
make oxygen, ATP and NADPH
<u>Do</u> <u>NOT</u> perform the C_3 (Calvin cycle) reactions

Bundle Sheath cells perform "UNusual" cyclic Light-Dependent Reactions
a lot of ATP but
very little NADPH
and *very little* O_2

PERFORM the usual C_3 (Calvin Cycle) reactions

C_4 leaf anatomy and the C_4 pathway





Mesophyll

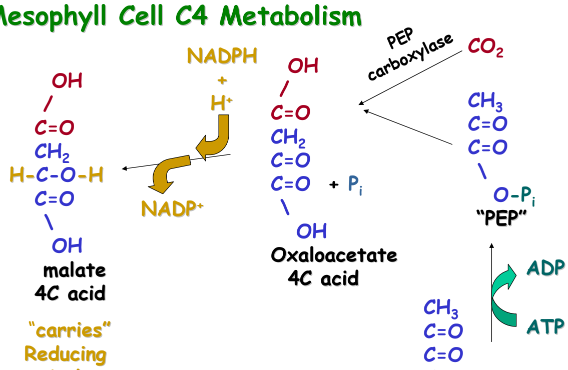
Produce NADPH and ATP

PEP carboxylase insensitive to O_2

Malate brings across reducing equivalents

Figure 10.19

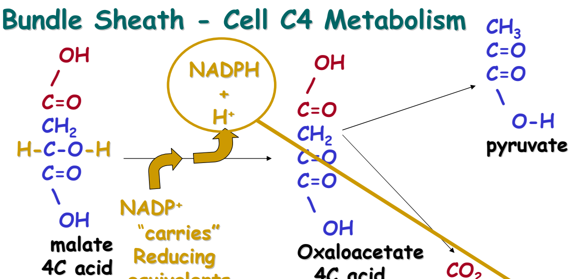
Mesophyll Cell C4 Metabolism



Needs ATP and NAPDPH + H+

Non-cyclic electron flow

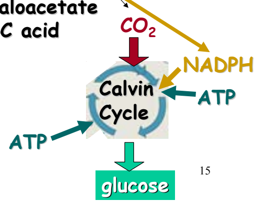
Bundle Sheath - Cell C4 Metabolism



Needs ATP Only

Cyclic electron flow

Very low O_2



Mesophyll cells provide a means for bundle sheath cells to acquire NADPH + H^+ reducing power

Mesophyll cells provide carbon dioxide to bundle sheath cells at higher concentration than in air

Bundle Sheath cells not making oxygen, so very little competitor with C_3 reactions

Costs more energy to do business this way…
but has the advantage when CO_2 is limiting
(when stomates are closed - like on hot days)

Who cares as long as the sun is shining ?
ATP is not limiting

CAM Plants

Cacti, pineapple

- Open their stomata only at night, too hot during day – survive very adverse (dry) conditions

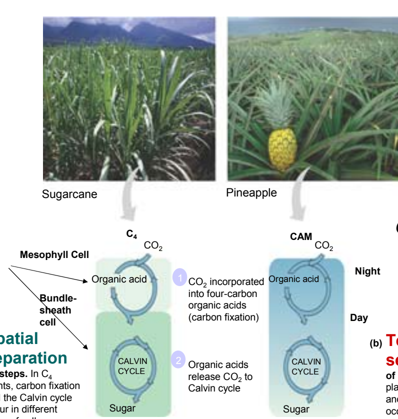
NIGHT
Perform PEP carboxylase reaction at night (CO_2 assimilation)
accumulate malate to high concentration in central vacuole
use sugar oxidation/catabolism to power (NADH and ATP) carbon fixation

DAY
Perform "light" reactions during the day
mostly cyclic e^- flow to produce ATP (low O_2)
decarboxylate malate to yield CO_2 and NADPH + H^+
perform C3 reactions (Calvin Cycle) to produce sugars and starch

Generally Slow growing

Sunlight Powers Both phases

Sugar Oxidation Powers One Phase



(a) Spatial separation of steps. In C_4 plants, carbon fixation and the Calvin cycle occur in different types of cells.

(b) Temporal separation of steps. In CAM plants, carbon fixation and the Calvin cycle occur in the same cells at different times.

Figure 10.20

Summary

1. Photosynthetic "light" reactions produce
   ATP and reducing potential NADPH + H^+

2. Dark reactions use ATP and reducing potential
   to synthesize carbohydrates
   - powers *reduction* of 3-carbon *acid*
     to 3-carbon *aldehyde*
   - powers regeneration of starting material
     5-carbon di-phosphate (priming step for CO_2 fixation)

3. Rubisco enzyme regulated *tightly* by allosteric modulators
   pH, and reducing status of stroma

4. O_2 interferes with carbon fixation by Rubisco enzyme

5. Metabolic "tricks" to avoid photorespiration
   - C4 metabolism - CAM metabolism