



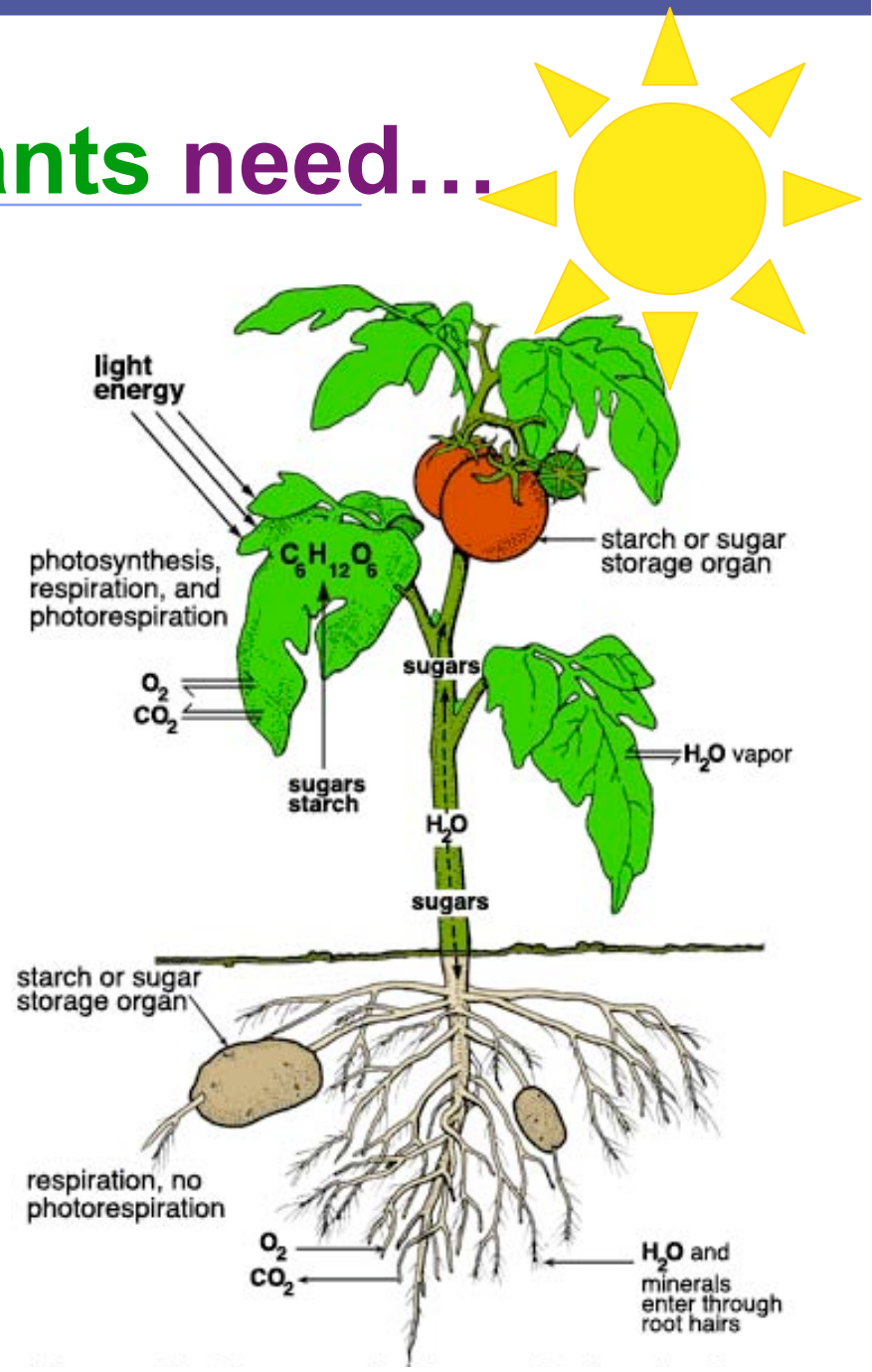
Chapter 10.
Photosynthesis:
Variations on the Theme

Remember what plants need...

- Photosynthesis
 - ◆ light reactions
 - ◆ Calvin cycle
 - light ← sun
 - H₂O ← ground
 - CO₂ ← air

What structures have plants evolved to supply these needs?

AP Biology

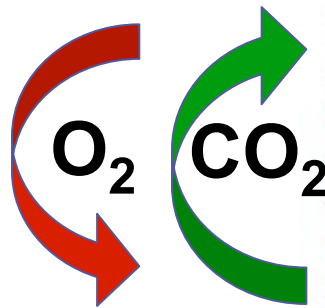


A second look at stomates...

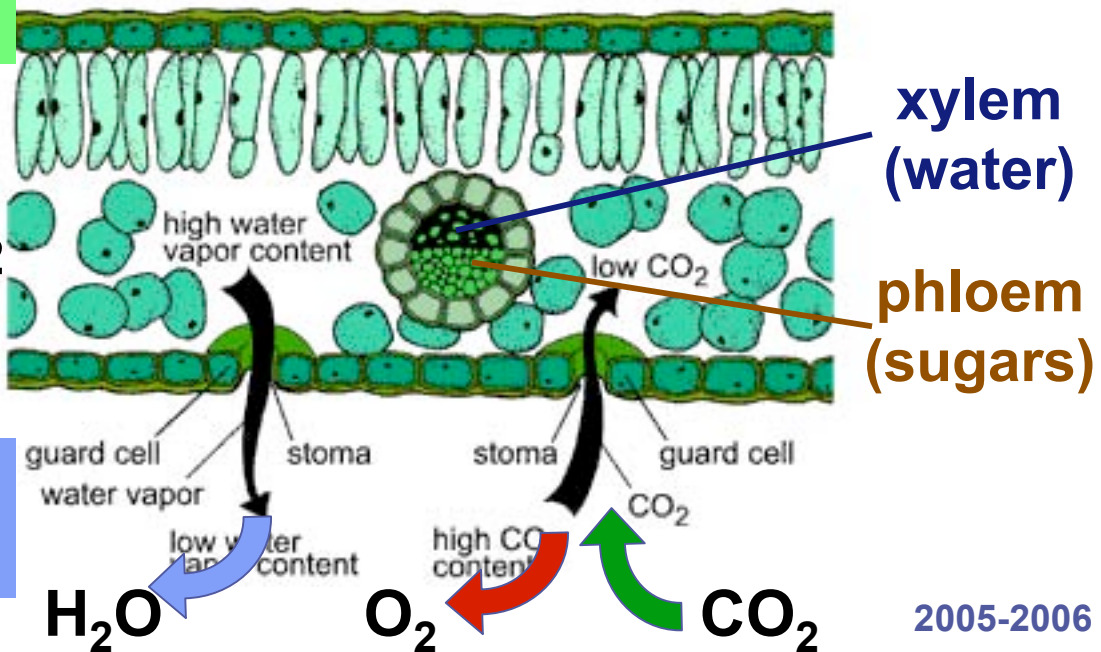
■ Gas exchange

- ◆ CO_2 in \rightarrow for Calvin cycle
- ◆ O_2 out \rightarrow from light reactions
- ◆ H_2O out \rightarrow for light reactions

photosynthesis



gas exchange
water loss



Controlling water loss from leaves

- **Hot or dry days**

- ◆ stomates close to conserve water

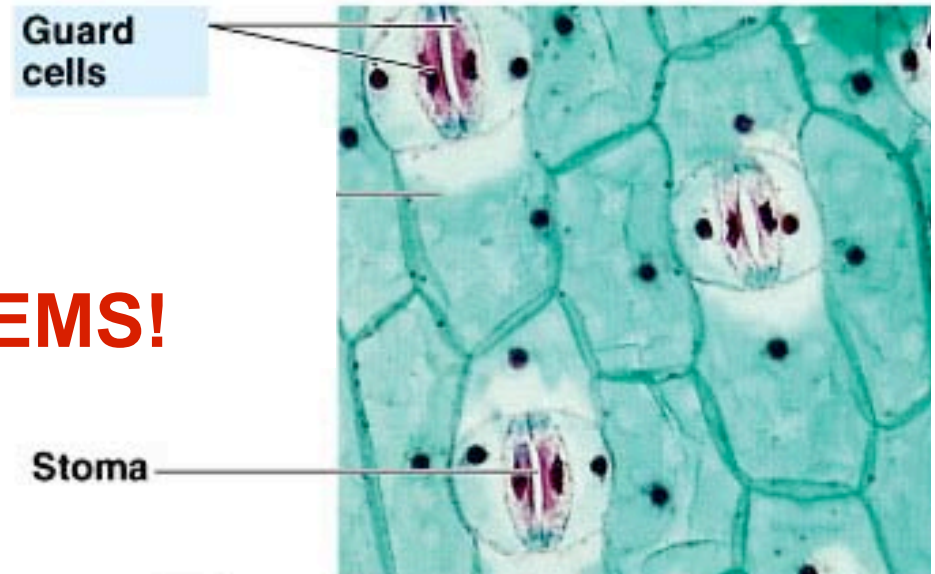
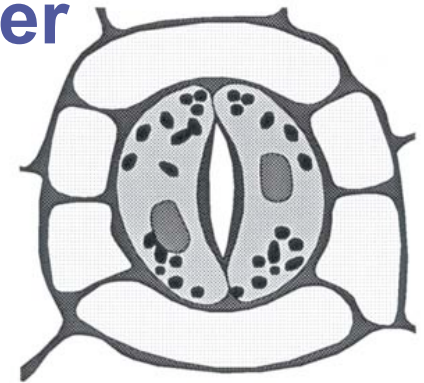
- ◆ guard cells

- gain H_2O = stomates open

- lose H_2O = stomates close

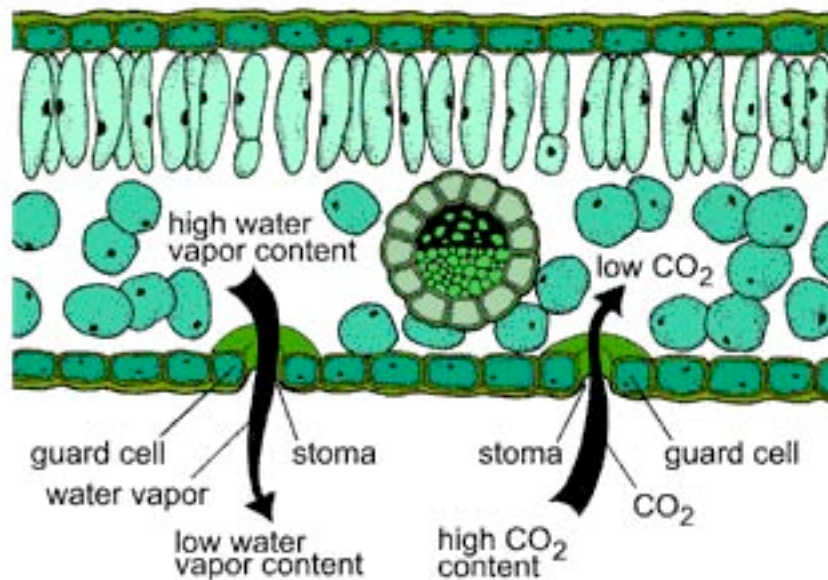
- ◆ adaptation to living on land, but...

creates PROBLEMS!



Closed stomates

- closed stomates lead to...
 - ◆ O_2 builds up (from light reactions)
 - ◆ CO_2 is depleted (in Calvin cycle)
 - causes problems in Calvin Cycle



the best laid
schemes of
mice and men...
and plants



Inefficiency of Rubisco: CO₂ vs O₂

- **Rubisco in Calvin cycle**

- ◆ **carbon fixation enzyme**

- normally bonds **C** to **RuBP**
- reduction of RuBP
- building sugars

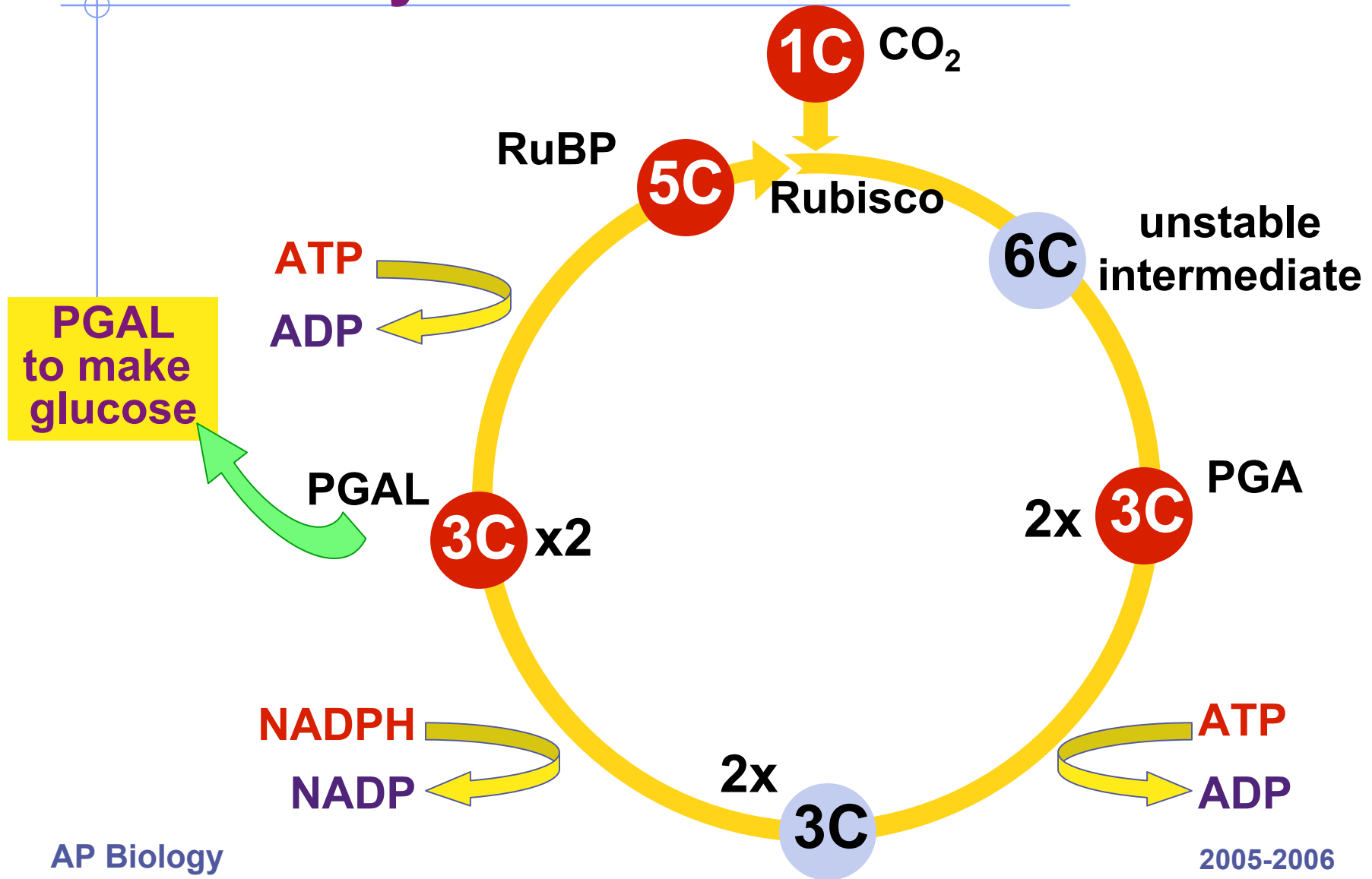
photosynthesis

- ◆ **when O₂ concentration is high**

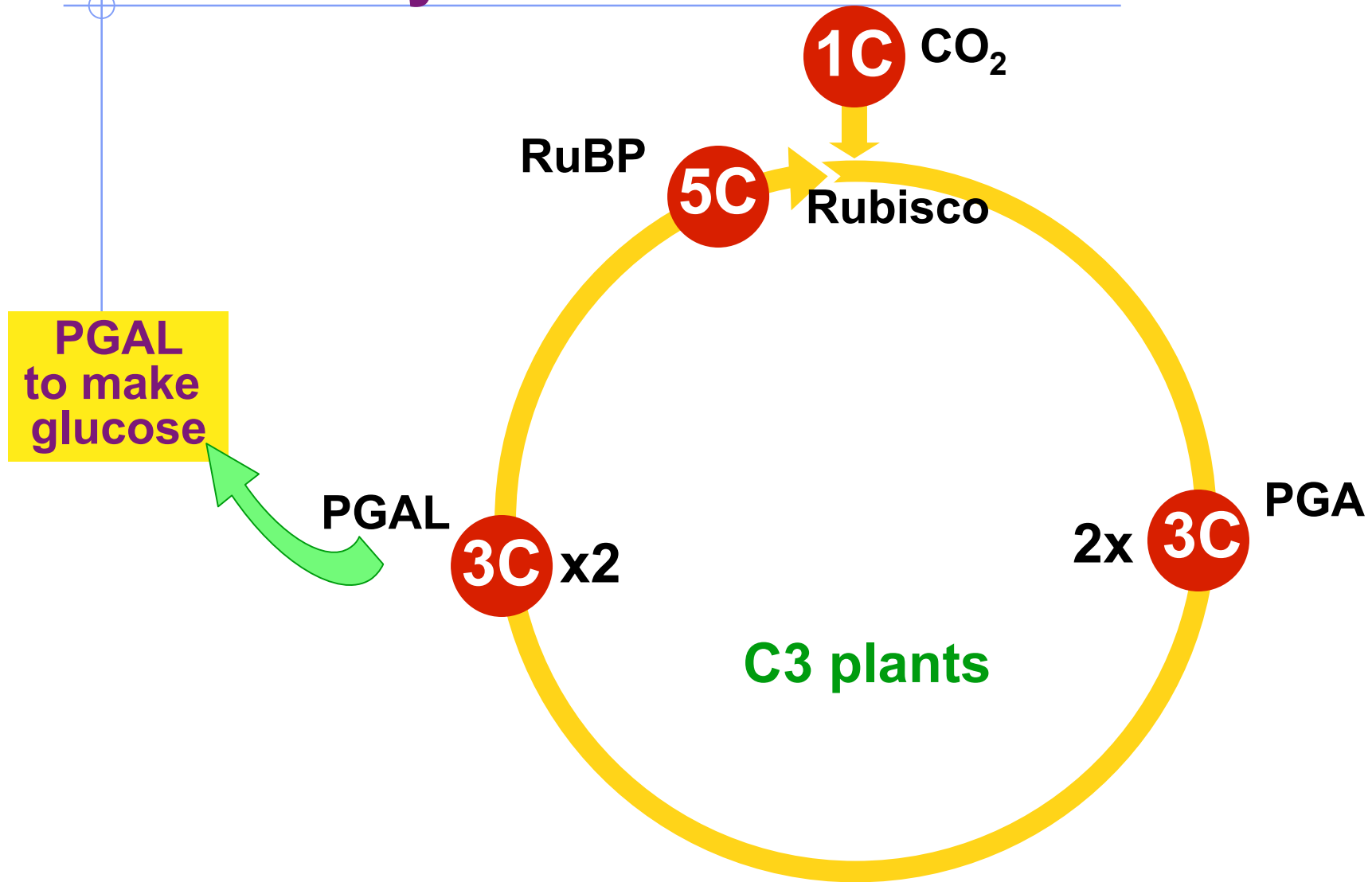
- Rubisco bonds **O** to **RuBP**
- **O₂** is alternative substrate
- oxidation of RuBP
- breakdown sugars

photorespiration

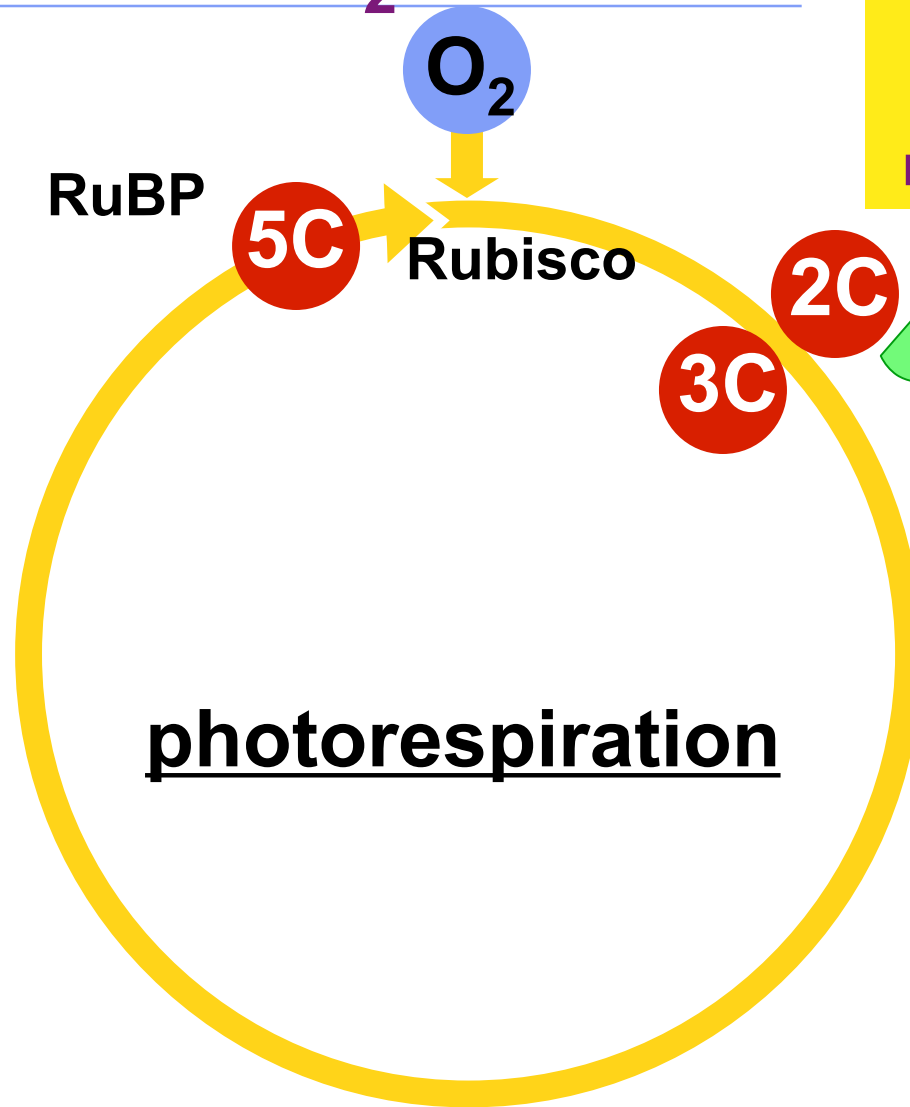
Calvin cycle review



Calvin cycle review



Calvin cycle with O₂



to
mitochondria

lost as CO₂
without
making ATP

a good
enzyme
goes bad...



Impact of Photorespiration

- **Oxidation of RuBP**
 - ◆ short circuit of Calvin cycle
 - ◆ loss of carbons to CO_2
 - can lose 50% of carbons fixed by Calvin cycle
 - ◆ decreases photosynthetic output by siphoning off carbons
 - no ATP (energy) produced
 - no $\text{C}_6\text{H}_{12}\text{O}_6$ (food) produced
 - ◆ if photorespiration could be reduced, plant would become 50% more efficient
 - strong selection pressure

Reducing photorespiration

- **Separate carbon fixation from Calvin cycle**
 - ◆ **C4 plants**
 - physically separate carbon fixation from Calvin cycle
 - different enzyme to capture CO_2
 - ◆ PEP carboxylase stores carbon in 4C compounds
 - different leaf structure
 - ◆ **CAM plants**
 - separate carbon fixation from Calvin cycle by time of day
 - fix carbon (capture CO_2) during night
 - ◆ store carbon in organic acids
 - perform Calvin cycle during day

C4 plants

- **A better way to capture CO₂**
 - ◆ before Calvin cycle, fix carbon with enzyme **PEP carboxylase**
 - store as 4-C compound
 - ◆ adaptation to hot, dry climates
 - have to close stomates a lot
 - different leaf anatomy
 - ◆ sugar cane, corn, other grasses...



C4 Plants



AP Biology

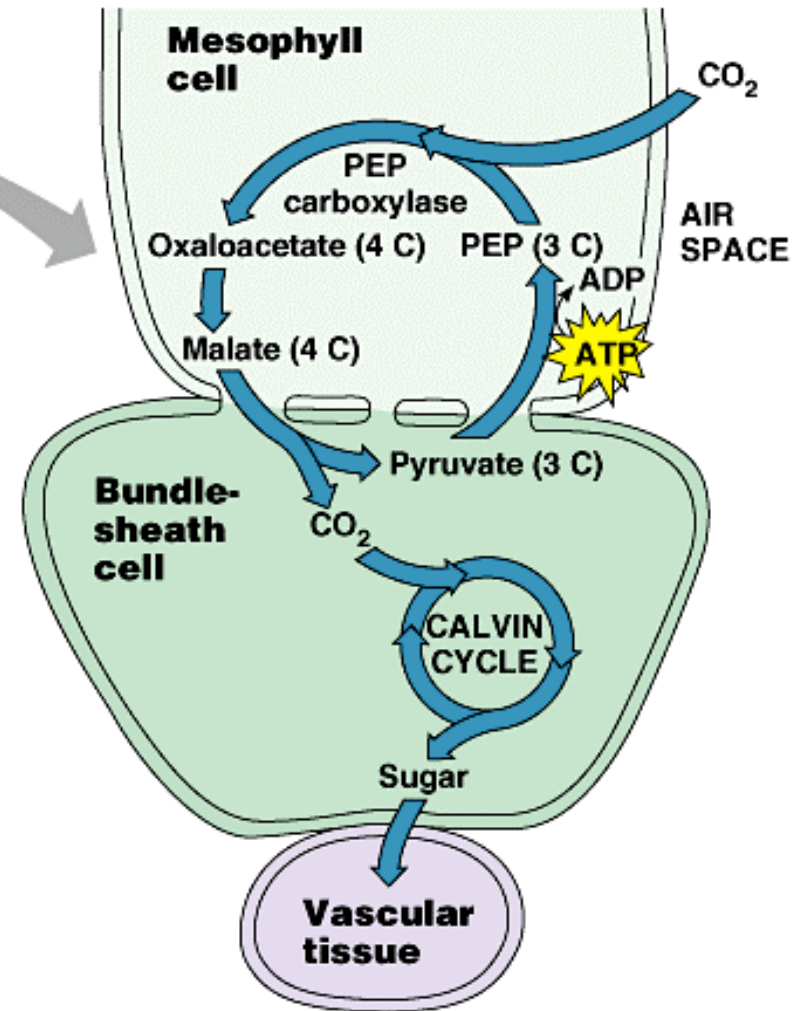
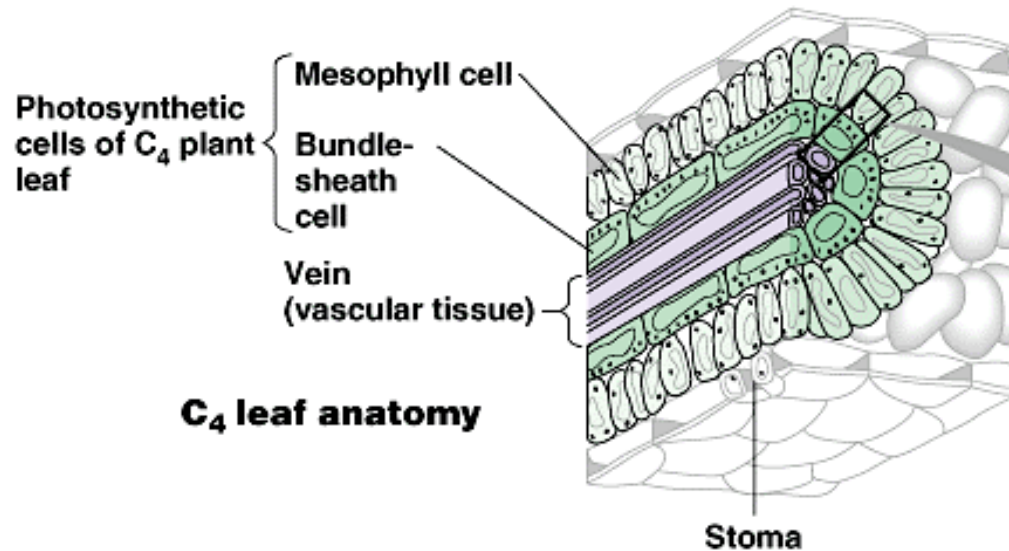
corn



sugar cane 005-2006

PEP carboxylase

light reactions → O₂



The C₄ pathway

■ PEP carboxylase enzyme

- ◆ higher affinity for CO₂ than O₂ (better than Rubisco)
- ◆ fixes CO₂ in 4C compounds
- ◆ regenerates CO₂ in inner cells for Rubisco



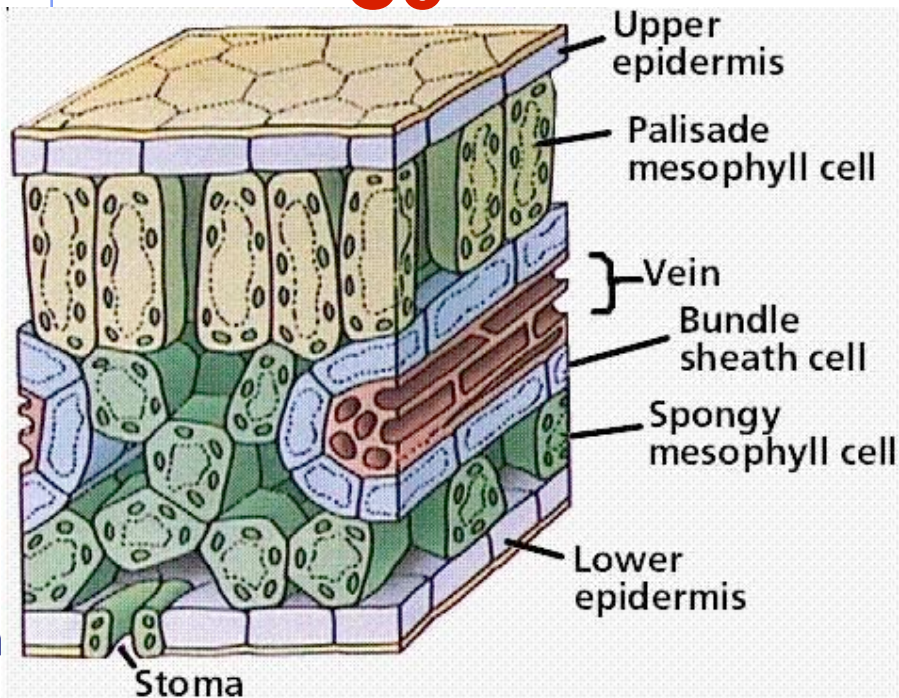
Comparative anatomy

- Separate reactions in different cells
 - ◆ light reactions
 - ◆ carbon fixation
 - ◆ Calvin cycle

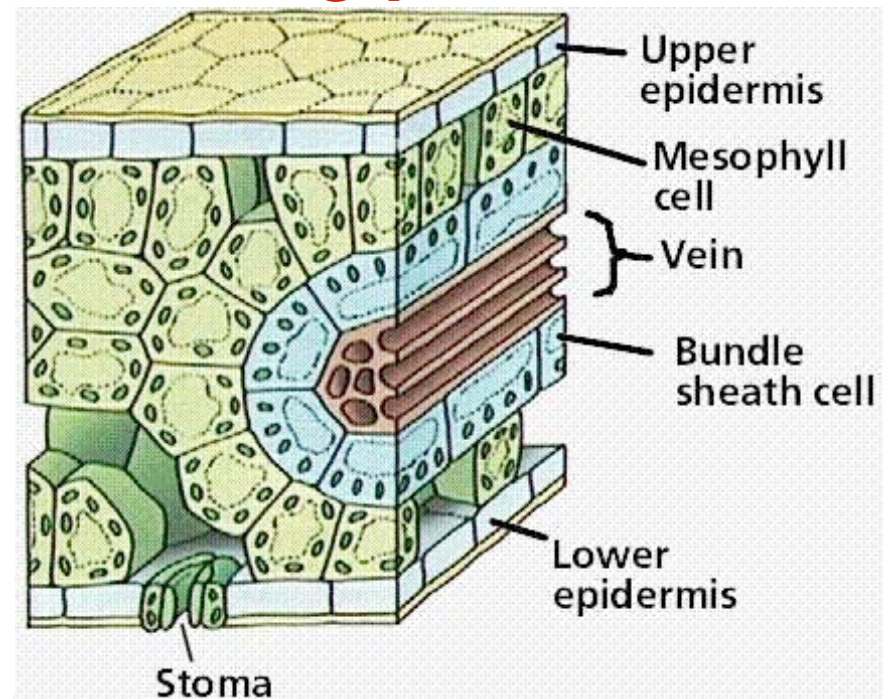
location,
location,
location...



C3

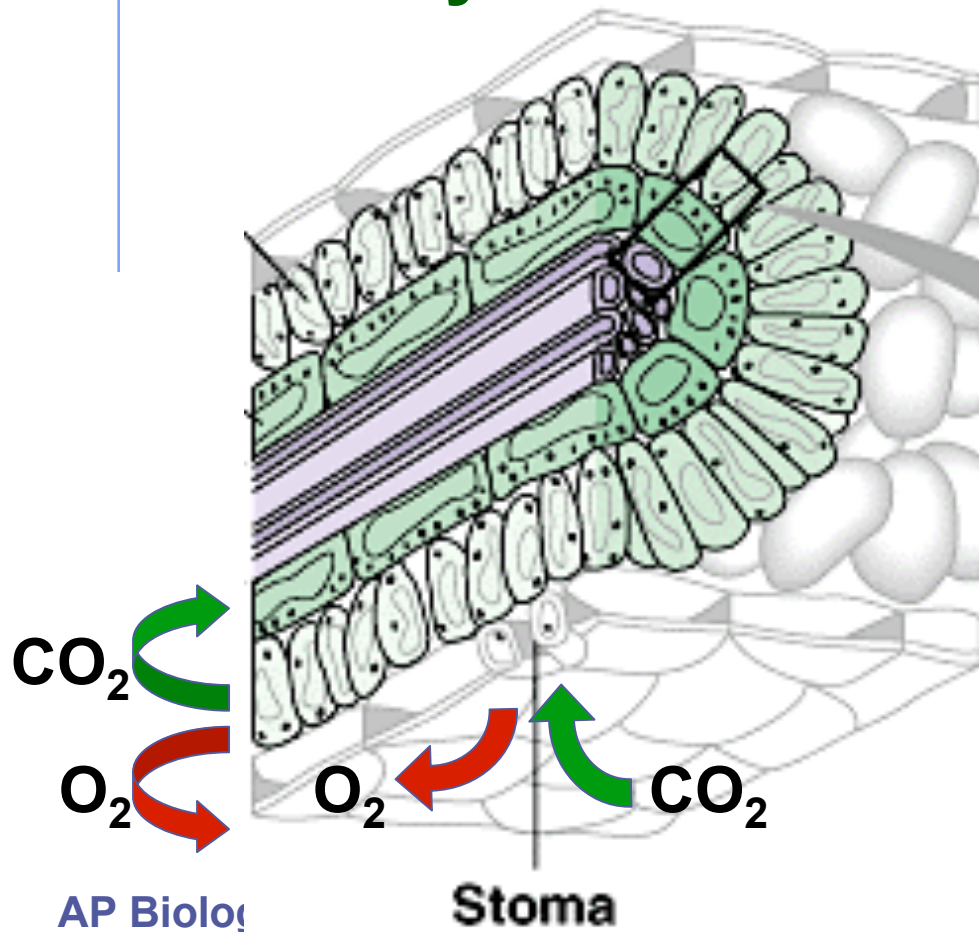


C4



C4 photosynthesis

Physically separated carbon fixation from Calvin cycle



■ Outer cells

- ◆ light reaction & carbon fixation
- ◆ pumps CO₂ to inner cells
- ◆ keeps O₂ away from inner cells
 - away from Rubisco

■ Inner cells

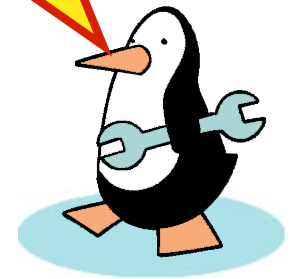
- ◆ Calvin cycle
- ◆ glucose to veins

2005-2006

CAM (Crassulacean Acid Metabolism) plants

- **Different adaptation to hot, dry climates**
 - ◆ succulents, some cacti, pineapple
 - ◆ **separate carbon fixation from Calvin cycle by time**
 - close stomates during day
 - open stomates during night
 - ◆ at night, open stomates & fix carbon in “storage” compounds
 - organic acids: malic acid, isocitric acid
 - ◆ in day, close stomates & release CO₂ from “storage” compounds to Calvin cycle
 - increases concentration of CO₂ in cells

it's all in
the timing...



CAM plants



C4 vs CAM Summary

☞ solves CO_2 / O_2 gas exchange vs. H_2O loss challenge

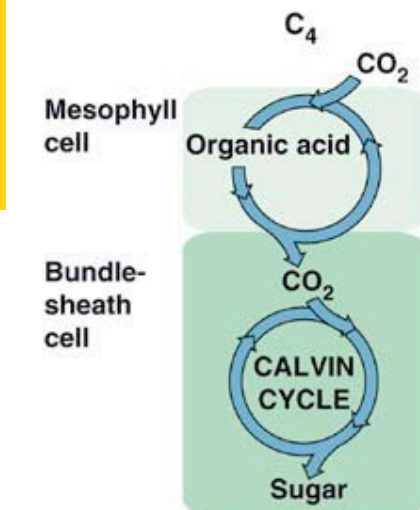


Sugarcane



Pineapple

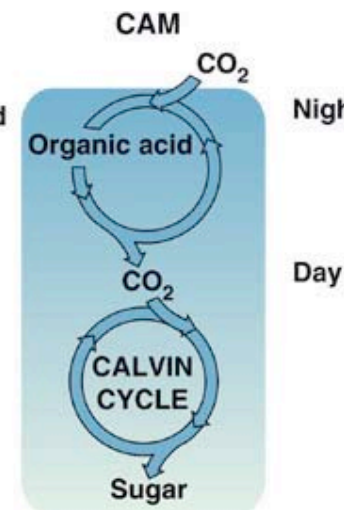
C4 plants
separate 2 steps
of C fixation
anatomically in
2 different cells



1 CO_2 incorporated into four-carbon organic acids (carbon fixation)

2 Organic acids release CO_2 to Calvin cycle

CAM plants
separate 2 steps
of C fixation
temporally at
2 different times



Night

Day

Why the C3 problem?

- **Possibly evolutionary baggage**
 - ◆ Rubisco evolved in high CO₂ atmosphere
 - there wasn't strong selection against active site Rubisco accepting both CO₂ & O₂
- **Today it makes a difference**
 - ◆ 21% O₂ vs. 0.03% CO₂
 - ◆ photorespiration can drain away 50% of carbon fixed by Calvin cycle on a hot, dry day
 - ◆ strong selection pressure to evolve better way to fix carbon & minimize photorespiration

we've all got baggage...





Any Questions??