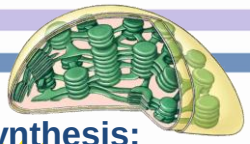
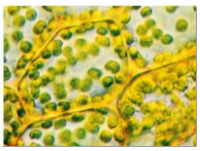


# Photosynthesis: Life from Light and Air



## Energy needs of life

- All life needs a constant input of energy
  - Heterotrophs (Animals)
    - get their energy from "eating others"
    - eat food = other organisms = organic molecules
    - make energy through respiration
  - Autotrophs (Plants)
    - produce their own energy (from "self")
    - convert energy of sunlight
    - build organic molecules ($CH_2O$) from $CO_2$
    - make energy & synthesize sugars through photosynthesis

consumers

producers



## How are they connected?

**Heterotrophs**

making energy & organic molecules from ingesting organic molecules

glucose + oxygen → carbon dioxide + water + energy

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + ATP$

oxidation = exergonic

**Autotrophs**

making energy & organic molecules from light energy

carbon dioxide + water + energy → glucose + oxygen

$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$

reduction = endergonic

# What does it mean to be a plant

- Need to…
  - collect light energy
    - transform it into chemical energy
  - store light energy
    - in a stable form to be moved around the plant or stored
  - need to get building block atoms from the environment
    - C,H,O,N,P,K,S,Mg
  - produce all organic molecules needed for growth
    - carbohydrates, proteins, lipids, nucleic acids

ATP

glucose

$CO_2$ $H_2O$ N K P …



# Plant structure

- Obtaining raw materials
  - sunlight
    - leaves = solar collectors
  - $CO_2$
    - stomates = gas exchange
  - $H_2O$
    - uptake from roots
  - nutrients
    - N, P, K, S, Mg, Fe…
    - uptake from roots

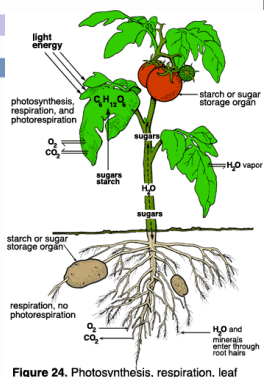



**Figure 24.** Photosynthesis, respiration, leaf water exchange, and translocation of sugar (photosynthate) in a plant.



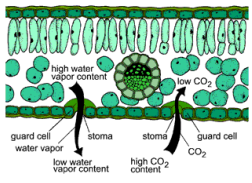
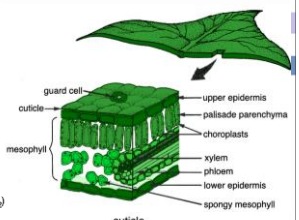
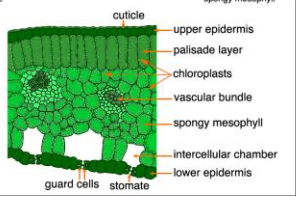



**Figure 25.** Stomata open to allow carbon dioxide ($CO_2$) to enter a leaf and water vapor to leave.

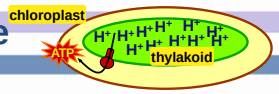




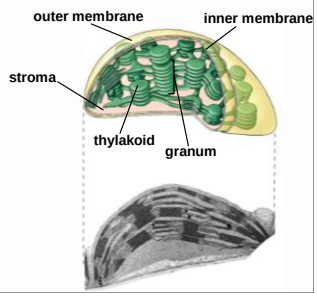
✓transpiration
✓gas exchange



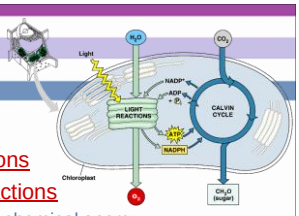
## Plant structure




- Chloroplasts
  - double membrane
  - stroma
    - fluid-filled interior
  - thylakoid sacs
  - grana stacks
- Thylakoid membrane contains
  - chlorophyll molecules
  - electron transport chain
  - ATP synthase
    - $H^+$ gradient built up within thylakoid sac




## Photosynthesis

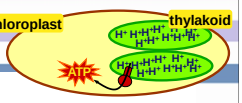



- Light reactions
  - light-dependent reactions
  - energy conversion reactions
    - convert solar energy to chemical energy
    - ATP & NADPH



- Calvin cycle
  - light-independent reactions
  - sugar building reactions
    - uses chemical energy (ATP & NADPH) to reduce $CO_2$ & synthesize $C_6H_{12}O_6$

## Light reactions



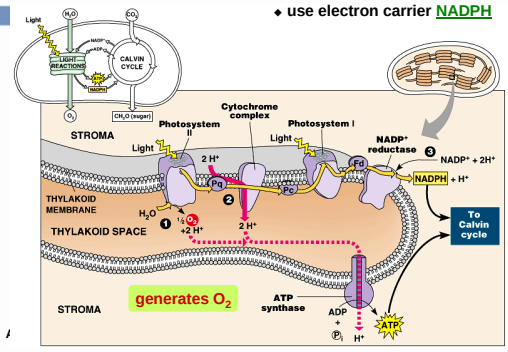

- Electron Transport Chain
  - like in cellular respiration
  - proteins in organelle membrane
  - electron acceptors
    - NADPH


  - proton ($H^+$) gradient across inner membrane
  - ATP synthase enzyme

## ETC of Photosynthesis

Chloroplasts transform light energy into chemical energy of ATP

- use electron carrier NADPH




## Light reactions

- Convert solar energy to chemical energy
  - ATP → **energy**
  - NADPH → **reducing power**
- What can we do now?



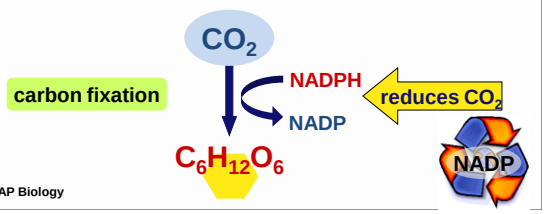
→ → **build stuff !!**

**photosynthesis**

AP Biology

## How is that helpful?

- Want to make $C_6H_{12}O_6$
  - synthesis
  - How? From what?
    What raw materials are available?




AP Biology

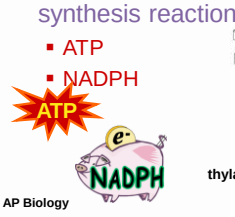
## From $CO_2 \rightarrow C_6H_{12}O_6$

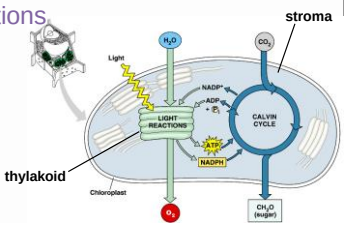
- $CO_2$ has very little chemical energy
  - fully oxidized
- $C_6H_{12}O_6$ contains a lot of chemical energy
  - highly reduced
- Synthesis = endergonic process
  - put in a lot of energy
- Reduction of $CO_2 \rightarrow C_6H_{12}O_6$ proceeds in many small uphill steps
  - each catalyzed by a specific enzyme
  - using energy stored in ATP & NADPH



## From Light reactions to Calvin cycle

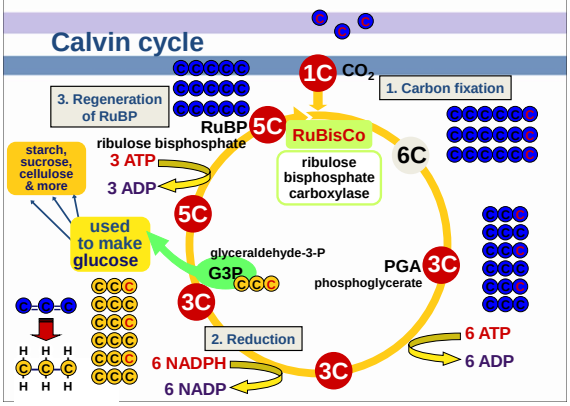
- Calvin cycle
  - chloroplast stroma
- Need products of light reactions to drive synthesis reactions
  - ATP
  - NADPH



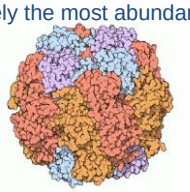



## Calvin cycle



## RuBisCo

- Enzyme which fixes carbon from air
  - ribulose bisphosphate carboxylase
  - the most important enzyme in the world!
    - it makes life out of air!
  - definitely the most abundant enzyme





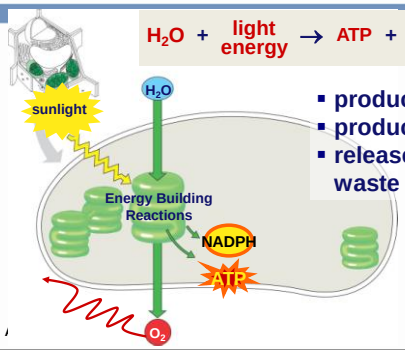
## Accounting

- The accounting is complicated
  - 3 turns of Calvin cycle = 1 G3P
  - 3 $CO_2$ → 1 G3P (3C)
  - 6 turns of Calvin cycle = 1 $C_6H_{12}O_6$ (6C)
  - 6 $CO_2$ → 1 $C_6H_{12}O_6$ (6C)
  - 18 ATP + 12 NADPH → 1 $C_6H_{12}O_6$
  - any ATP left over from light reactions will be used elsewhere by the cell



## Light Reactions

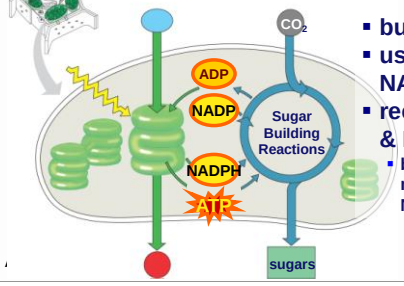
$H_2O$ + light energy → ATP + NADPH + $O_2$




- produces ATP
- produces NADPH
- releases $O_2$ as a waste product

## Calvin Cycle

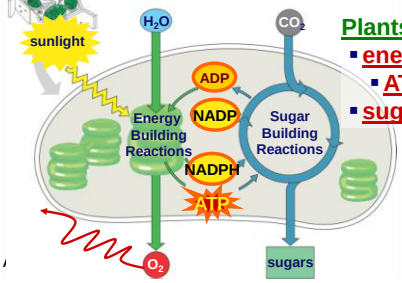
$CO_2 + ATP + NADPH \rightarrow C_6H_{12}O_6 + ADP + NADP$




- builds sugars
- uses ATP & NADPH
- recycles ADP & NADP
  - back to make more ATP & NADPH

## Putting it all together

$CO_2 + H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + O_2$




**Plants make both:**

- energy
  - ATP & NADPH
- sugars