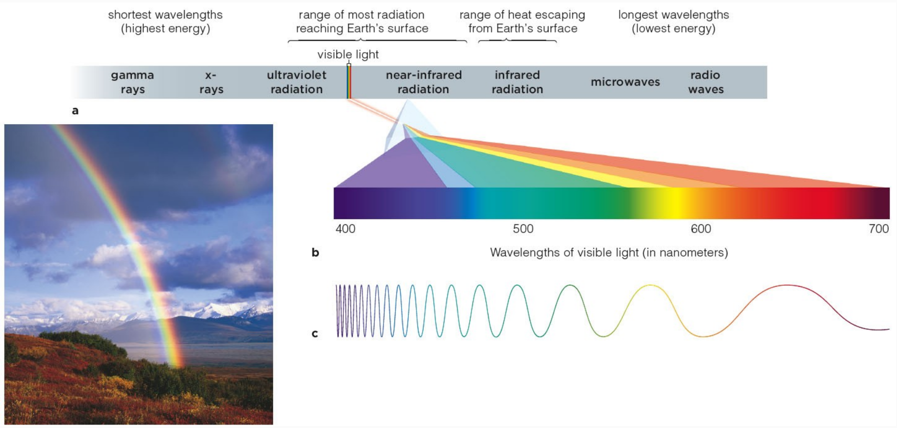
Chapter 6 - Photosynthesis

Sunlight as an Energy Source

- **Photosynthesis**
  - The synthesis of organic molecules from inorganic molecules using the energy of light

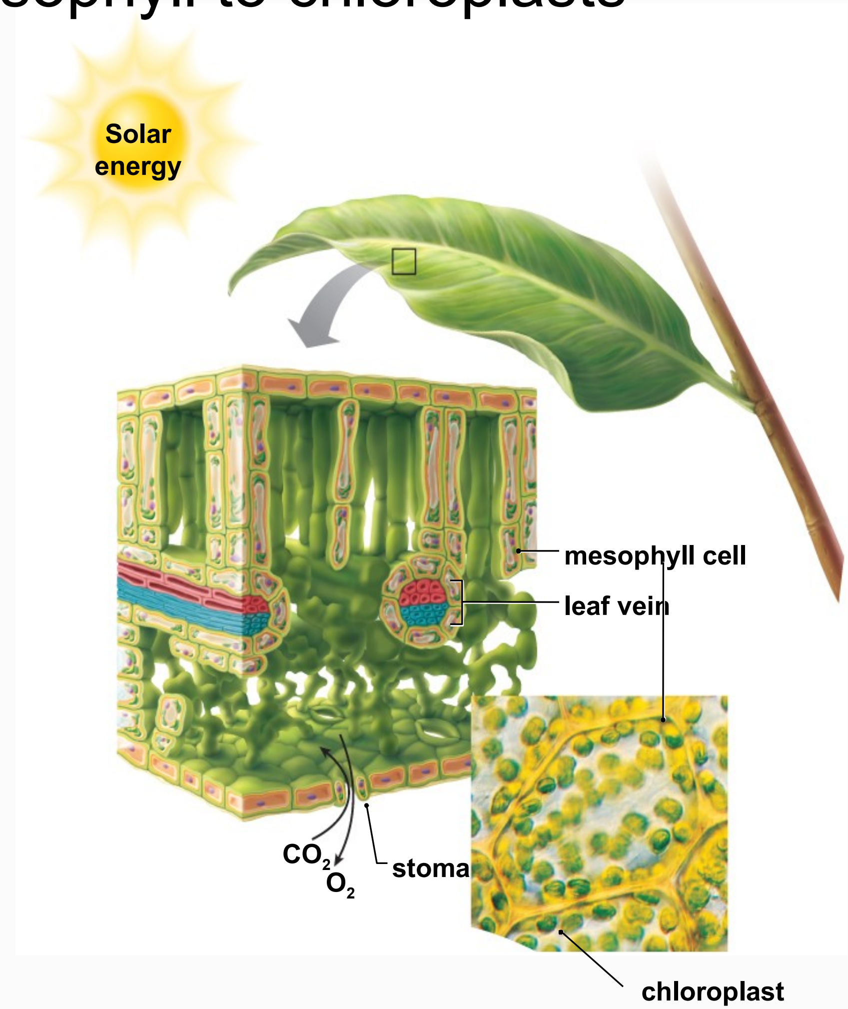


Sites of Photosynthesis in Plants

CO_2 enters through stomata to mesophyll to chloroplasts

O_2 exits through stomata

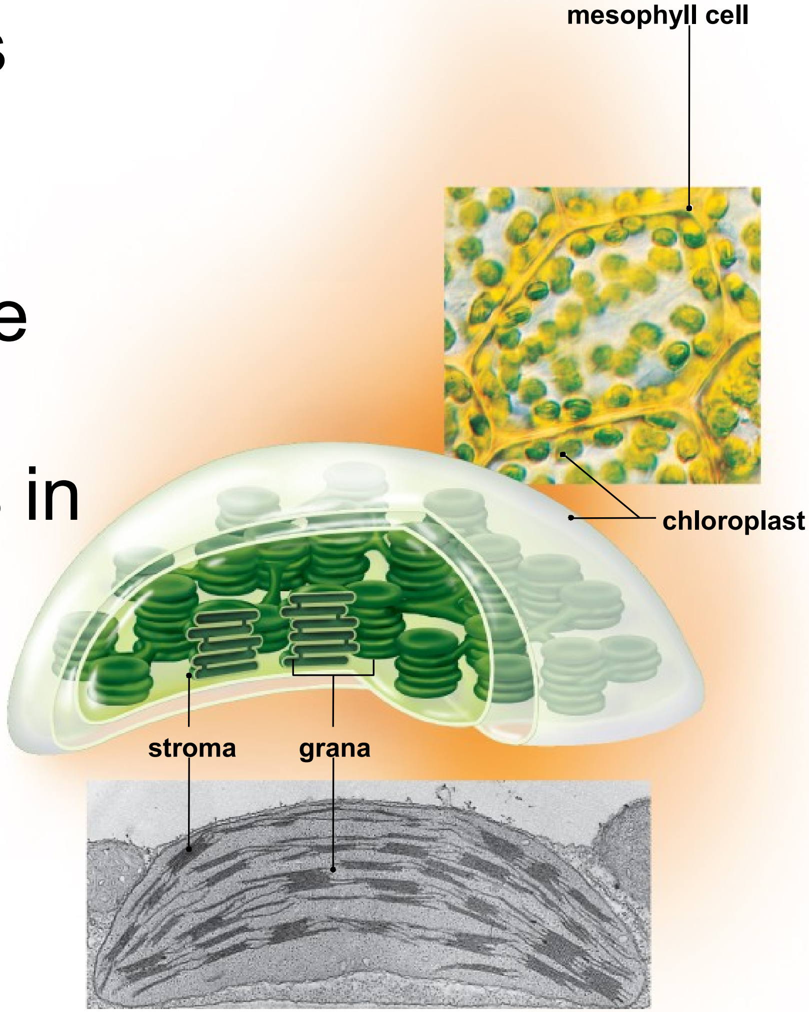
- **Chloroplast**
  - An organelle that specializes in photosynthesis in plants and many protists



Chloroplast close up

- Double membrane surrounds stroma
  - Semifluid matrix
  - Sugars (glucose) built here

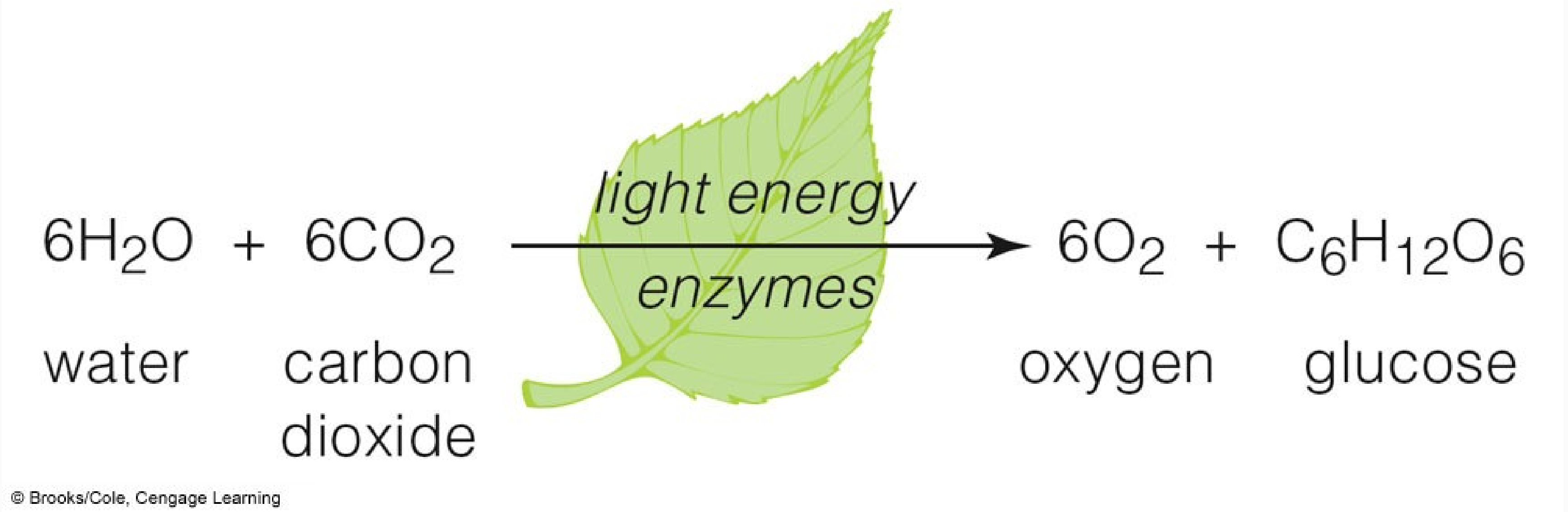
- Third membrane – thylakoids in stacks called grana
  - Chlorophyll and other pigments are found here
    - Pigments absorb solar energy



Courtesy Herbert W. Israel, Cornell University

Overview of Photosynthesis

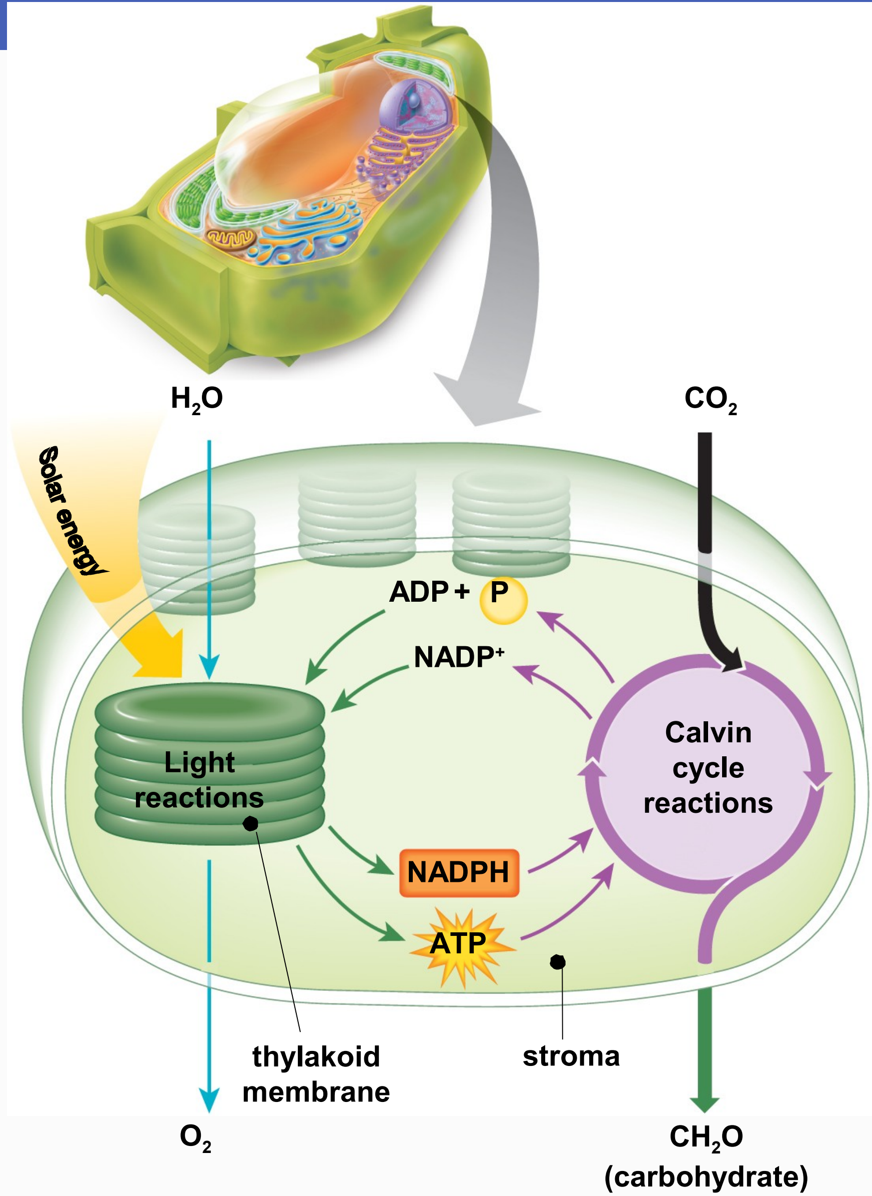
1. **Light-dependent reactions (thylakoid membrane)**
   - Light energy is transferred to ATP and NADPH
   - Water molecules are split, releasing O_2
1. **Light-independent reactions (stroma)**
   - Energy in ATP and NADPH drives synthesis of glucose and other carbohydrates from CO_2 and water



2 reactions in Photosynthesis

1. Light-dependent reactions

- In thylakoid membrane
- Chlorophyll (the main pigment) absorbs solar energy
- Electrons get excited!
- ATP produced
- $NADP^+$ to NADPH

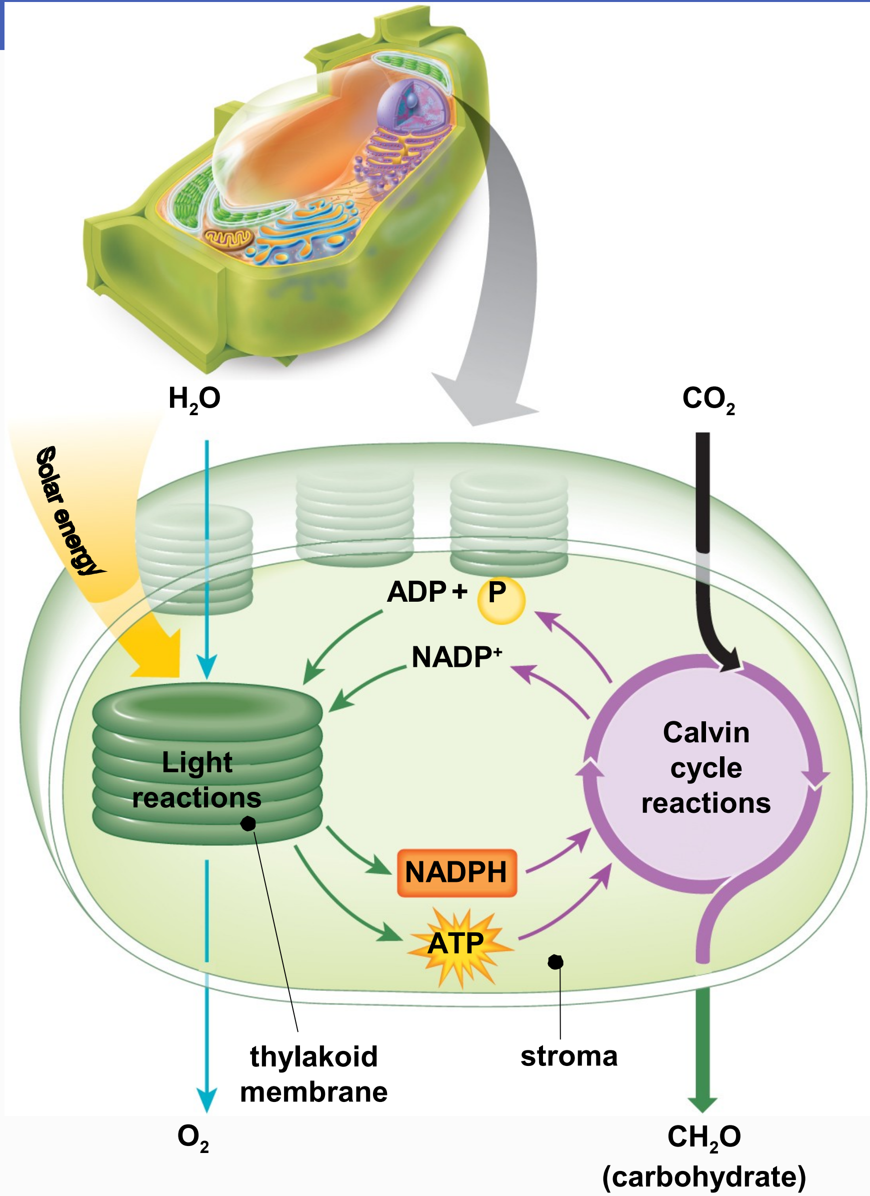


2 reactions in Photosynthesis

2. Light-independent reactions (Calvin cycle)

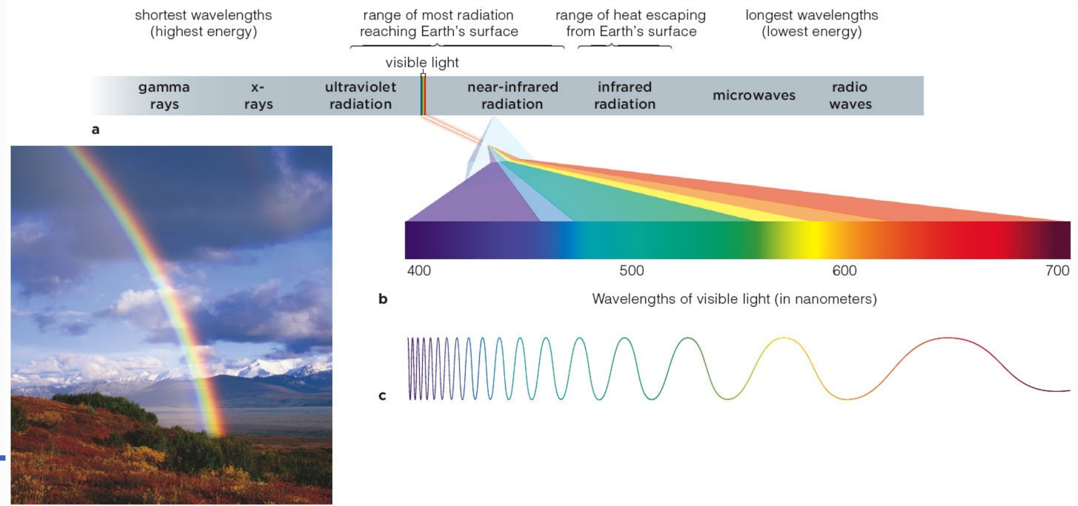
- Occur in stroma
- CO_2 taken up
- ATP and NADPH used to form carbohydrate from CO_2

http://www.youtube.com/v/C1_uez5WX1o



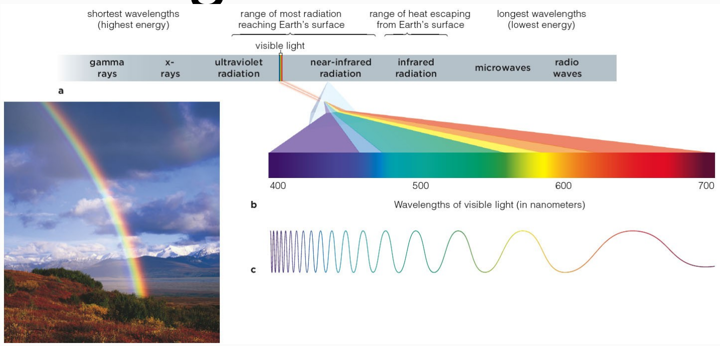
Light-Dependent Reactions: 1. Pigments

- **Pigments in thylakoids absorb solar energy**
  - Only about 42% of the solar radiation hits the Earth's surface
    - Ozone layer
    - Water vapor
- Vision and photosynthesis are adapted to use the wavelengths that hit the Earth!



Light-Dependent Reactions: 1. Pigments

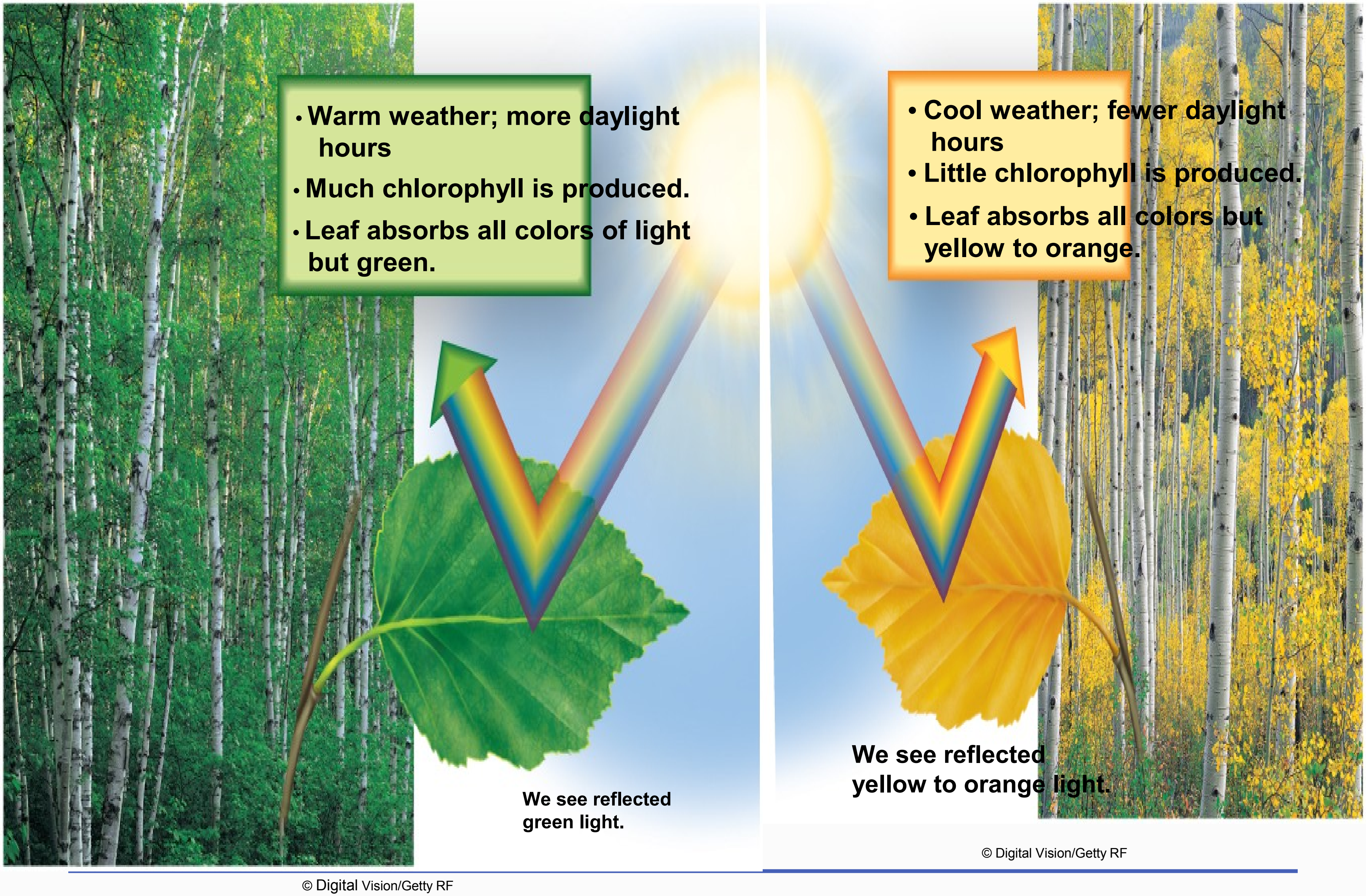
- Photosynthesis uses wavelengths of 380-750 nm
- Color you see are the wavelengths *not* absorbed – why the ocean is blue and leaves are green!!!



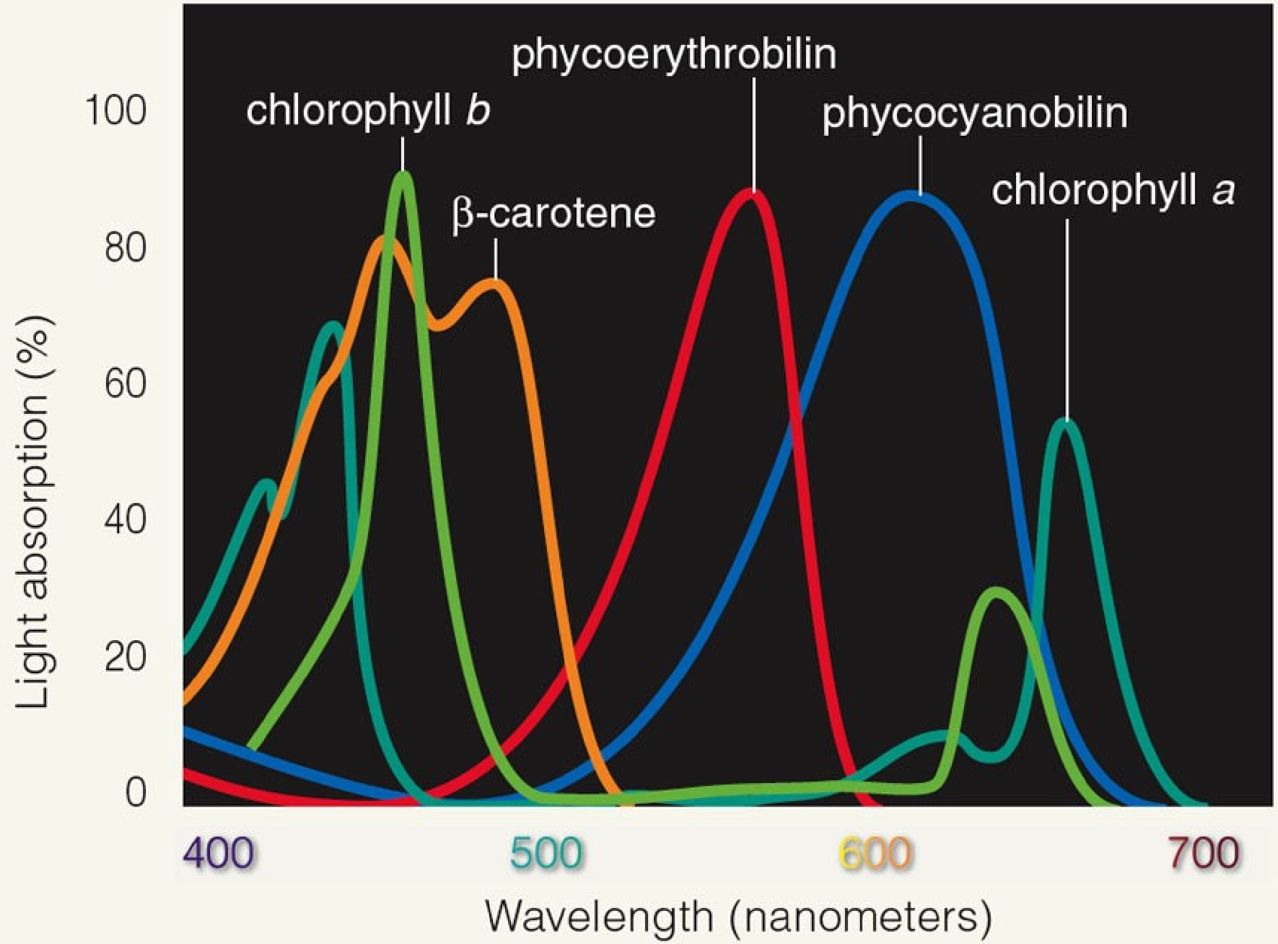
- **Chlorophyll (a & b)**
  - The most common photosynthetic pigment
  - Absorbs violet and red light (appears green)
  - Carotenoids – an accessory pigment found in photosynthesizers

Chlorophylls cover up other pigments that ARE there.

When chlorophylls no longer produced, we see carotenoids



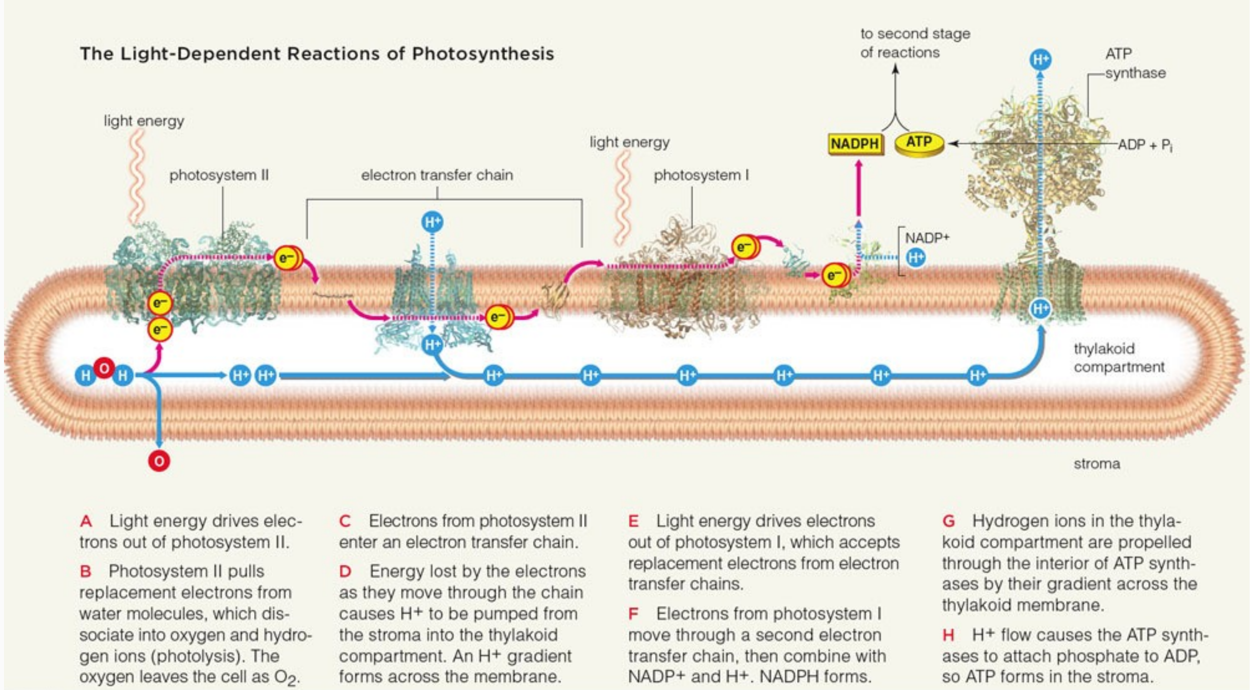
Why are accessory pigments important???



C Absorption spectra of a few photosynthetic pigments. Line color indicates the characteristic color of each pigment.

http://www.youtube.com/v/IJCVg9M-7S0

The Light Reactions – 2. The electron pathway

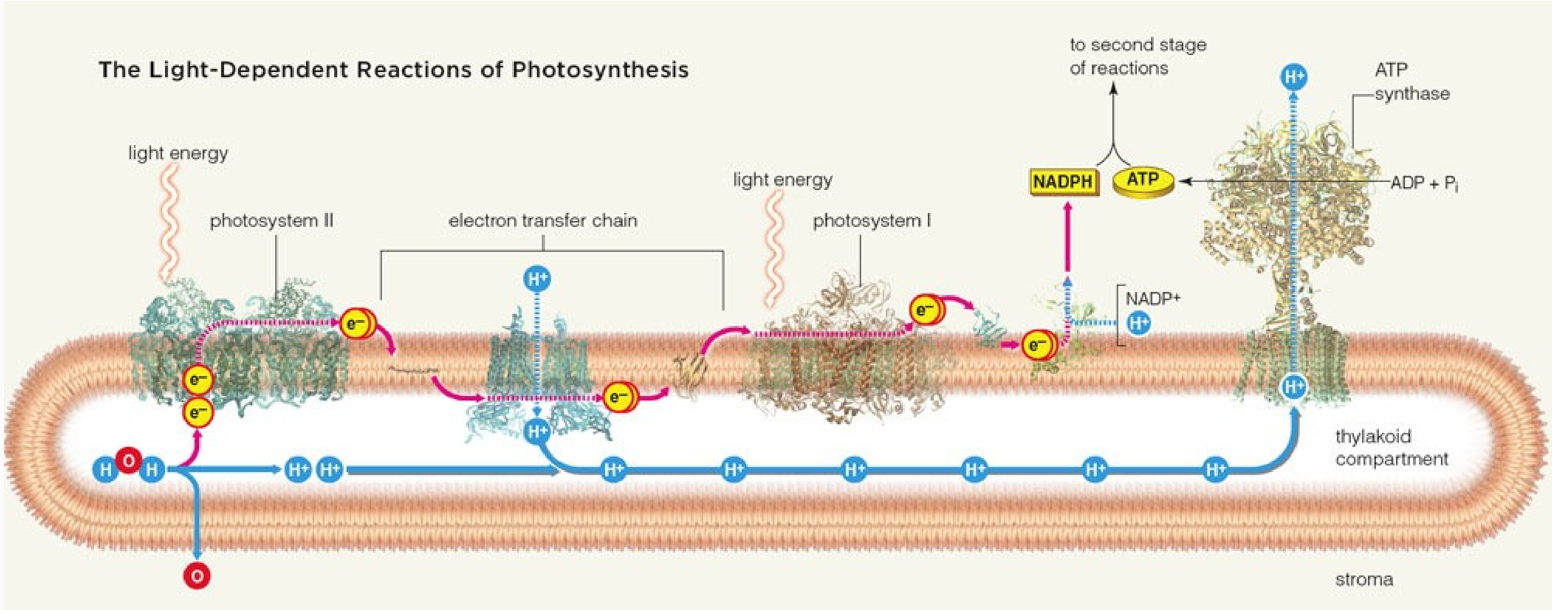


- 2 photosystems used
  - PS II & PS I
    - Pigment complexes & e- acceptor
    - e- move down e- transport chain
    - PS II first one discovered
    - PS I NADP$^+$ becomes NADPH

Where do replacement electrons come from???

The Light Reactions: 3. Replacing Lost Electrons

- Electrons lost from photosystem II are replaced by splitting of water molecules
  - O_2 & H^+ ions released



A Light energy drives electrons out of photosystem II.

B Photosystem II pulls replacement electrons from water molecules, which dissociate into oxygen and hydrogen ions (photolysis). The oxygen leaves the cell as O_2.

C Electrons from photosystem II enter an electron transfer chain.

D Energy lost by the electrons as they move through the chain causes H+ to be pumped from the stroma into the thylakoid compartment. An H+ gradient forms across the membrane.

E Light energy drives electrons out of photosystem I, which accepts replacement electrons from electron transfer chains.

F Electrons from photosystem I move through a second electron transfer chain, then combine with NADP+ and H+. NADPH forms.

G Hydrogen ions in the thylakoid compartment are propelled through the interior of ATP synthases by their gradient across the thylakoid membrane.

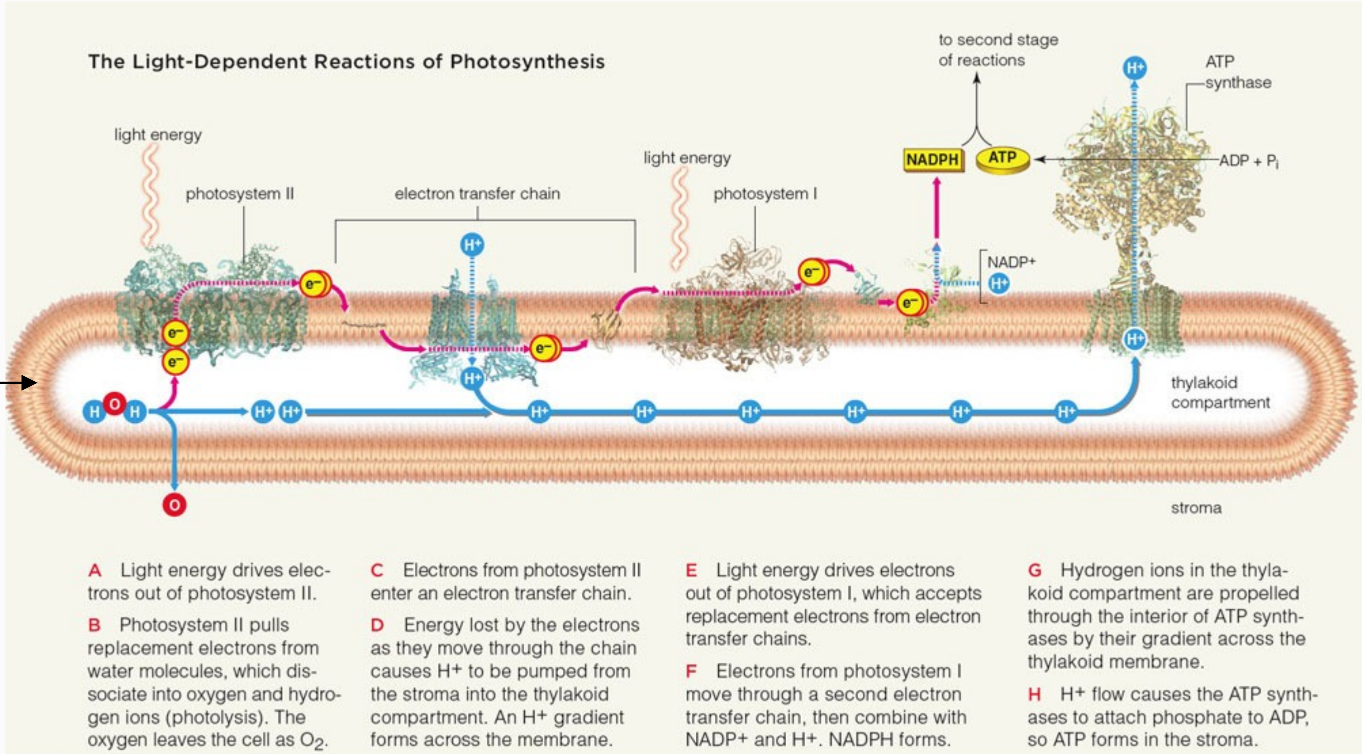
H H+ flow causes the ATP synthases to attach phosphate to ADP, so ATP forms in the stroma.

The Light Reactions: 4. The electron transport chain

- Organized arrays of enzymes, coenzymes, and other proteins that accept and donate electrons in a series
  - Energy released at each “step”.
  - H^+ gradient
  - Efficient

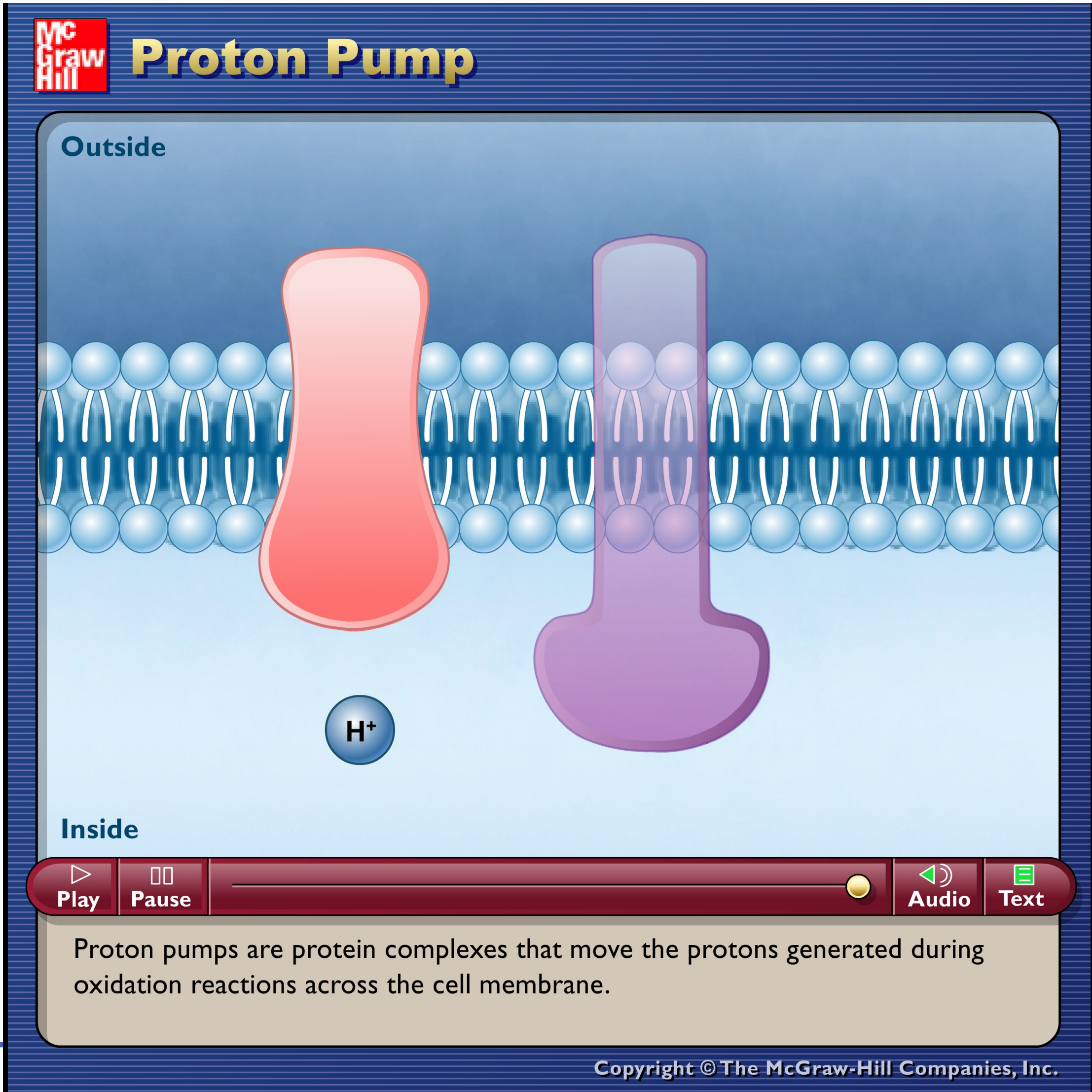
transfer of e-

Thylakoid membrane

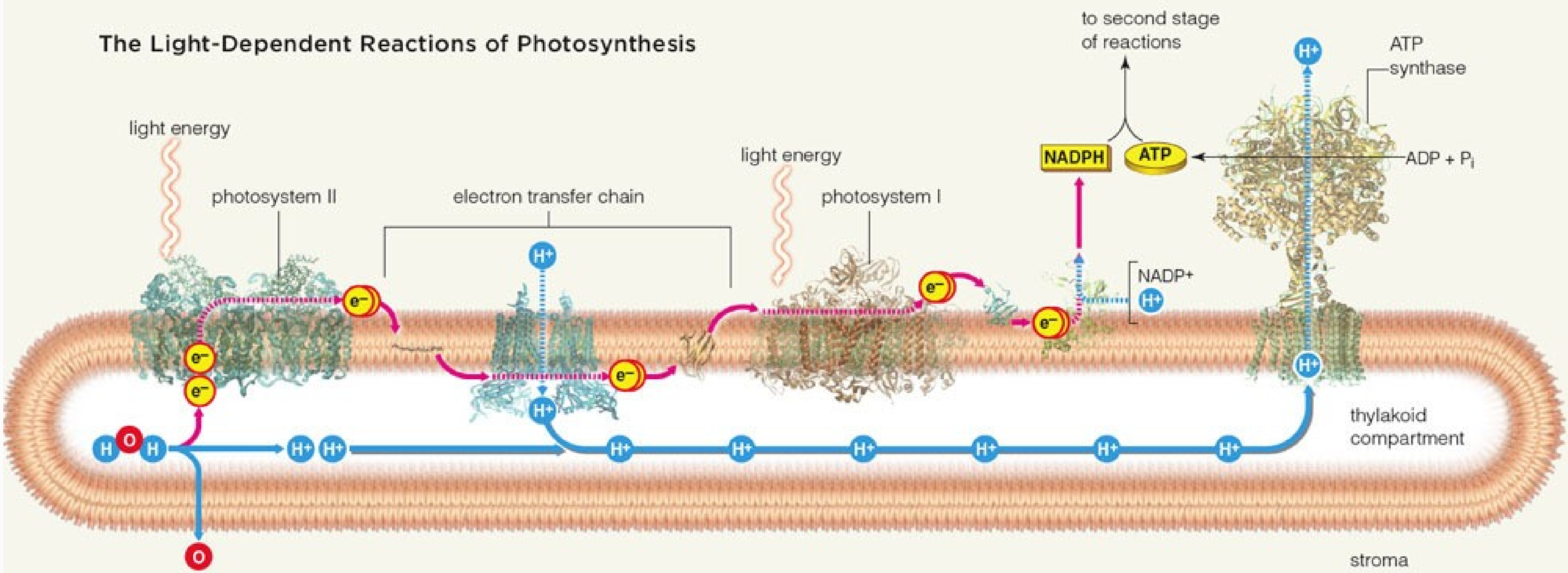


The Light Reactions: 5. Harvesting Electron Energy

- ATP Production
  - ATP synthase complex is also on thylakoid membrane
  - Many H^+ in thylakoid space
    - Water split
    - H^+ pumped in from stroma
    - H^+ gradient formed
    - Where do H^+ want to go???



Light reactions of Photosynthesis



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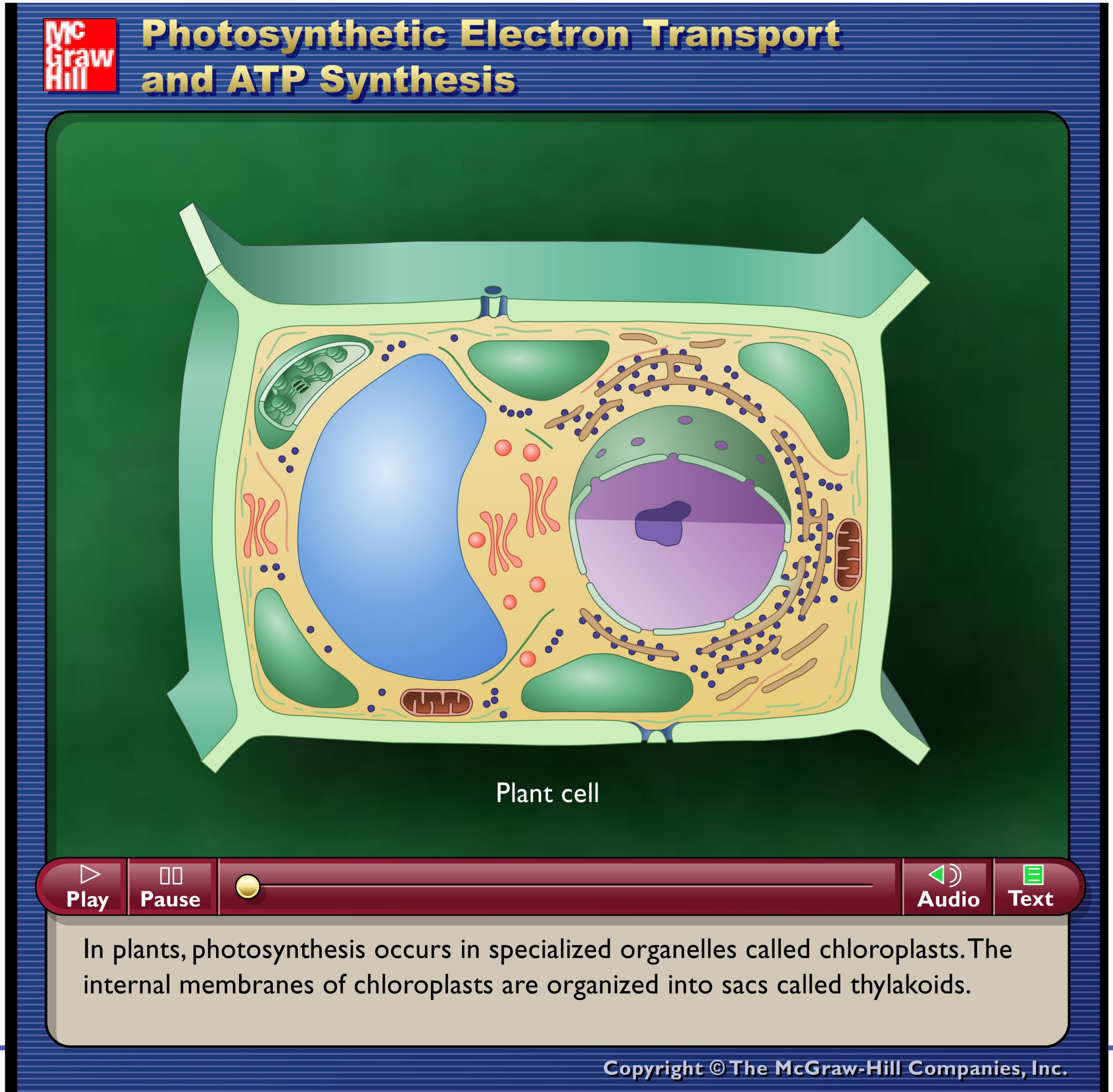
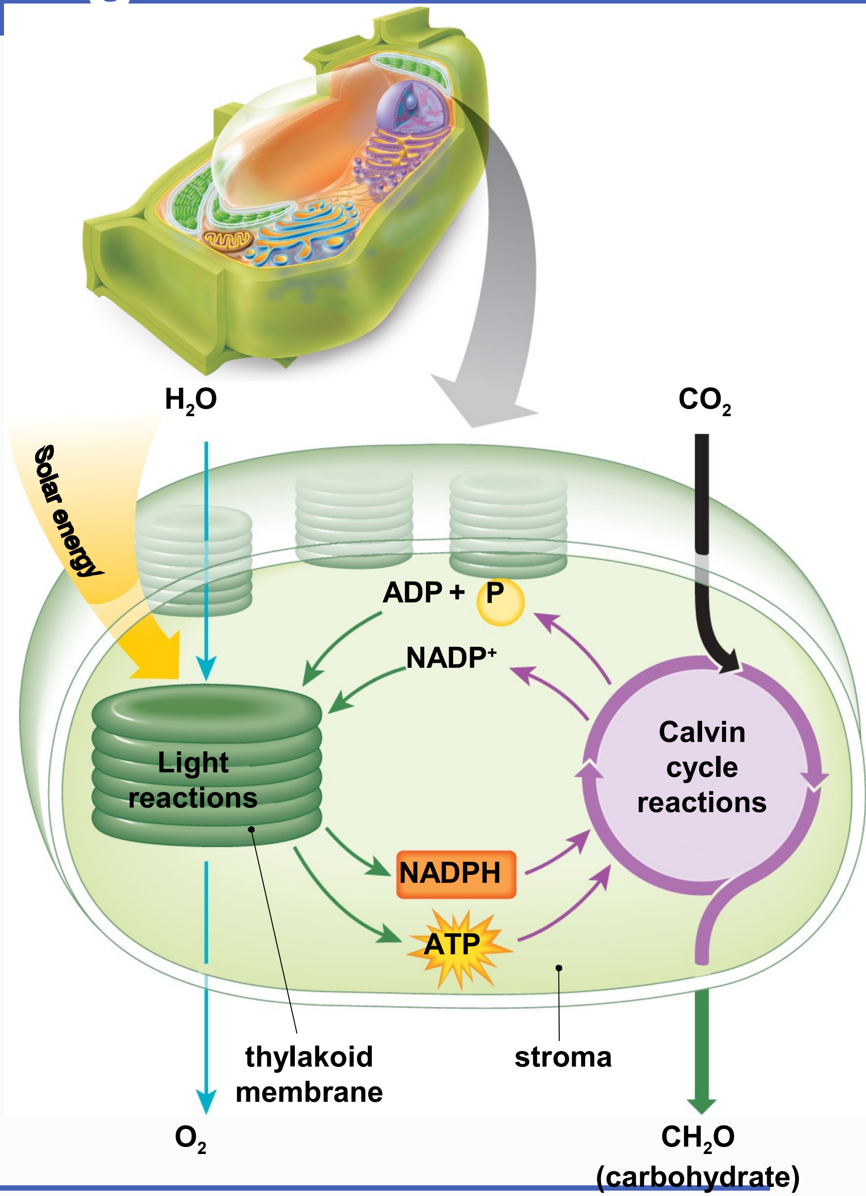
ATP forms in the stroma when H^+ ions travel through ATP synthase

Animation: Light-dependent reactions



Light-Independent Reactions: The Calvin Cycle – making sugars!

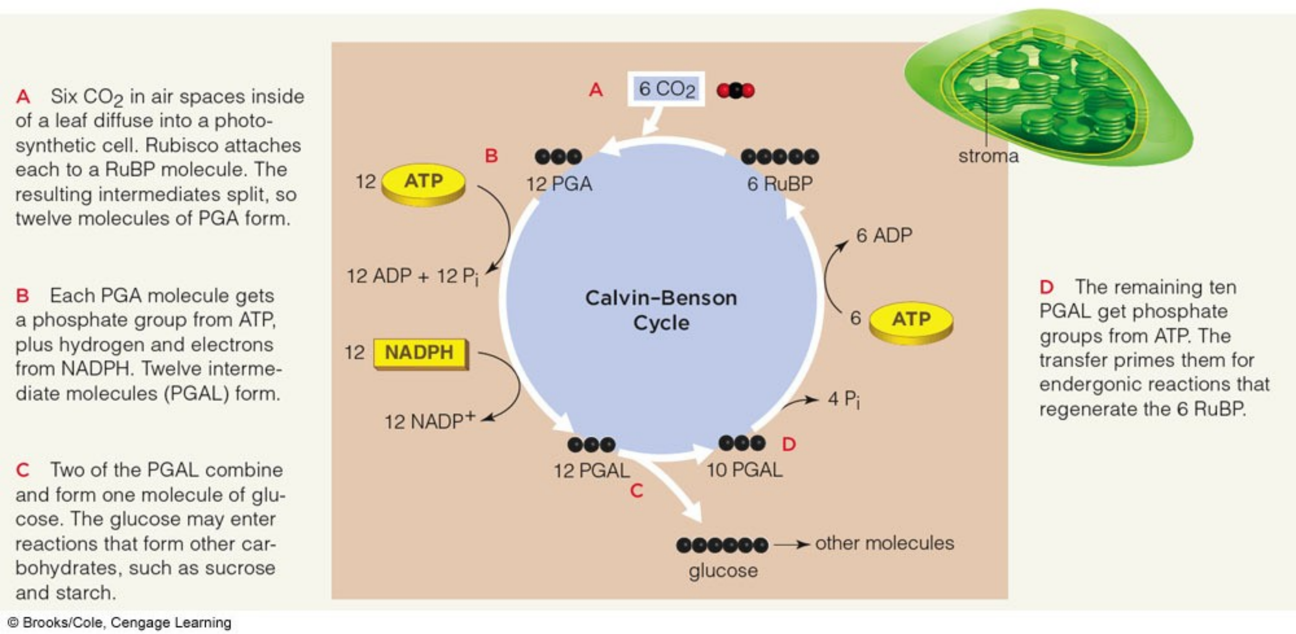
- **Calvin cycle**
  - Rxns that build sugars in stroma
  - Powered by ATP & NADPH
  - End product is glucose: $C_6H_{12}O_6$



The Calvin Cycles' 3 Steps

1. Carbon dioxide fixation
2. Carbon dioxide reduction
3. Regeneration of 1st substrate (RuBP)

1. Carbon dioxide fixation
   - Enzyme **rubisco** attaches CO_2 to RuBP forming 6 carbon molecule
   - 6 carbon molecule splits into two 3 carbon molecules (PGA)



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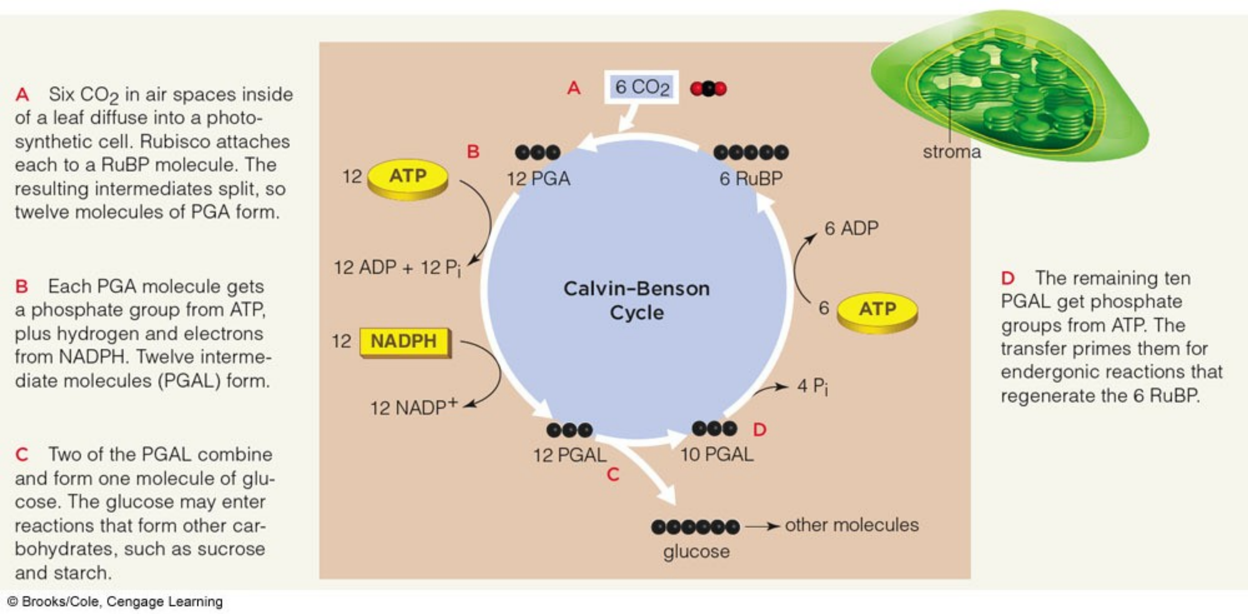

2. Carbon dioxide reduction
   - PGA converted into PGAL (G3P) using NADPH (for H) and ATP (energy)
   - PGAL (G3P) can become glucose

The Calvin Cycles’ 3 Steps

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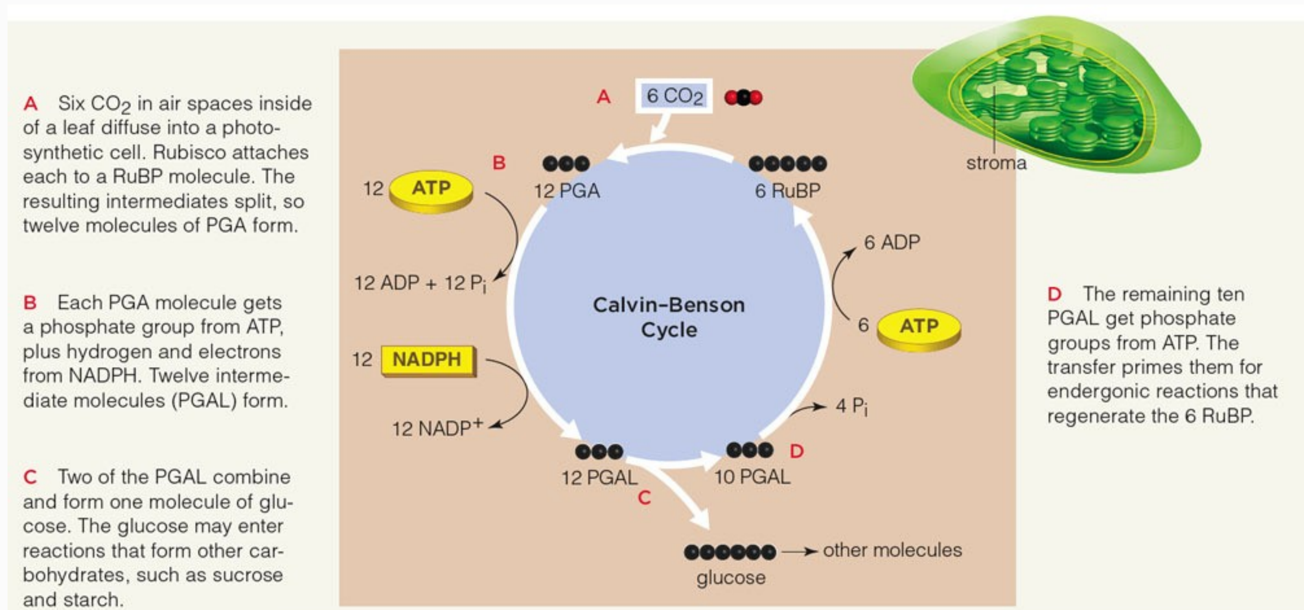
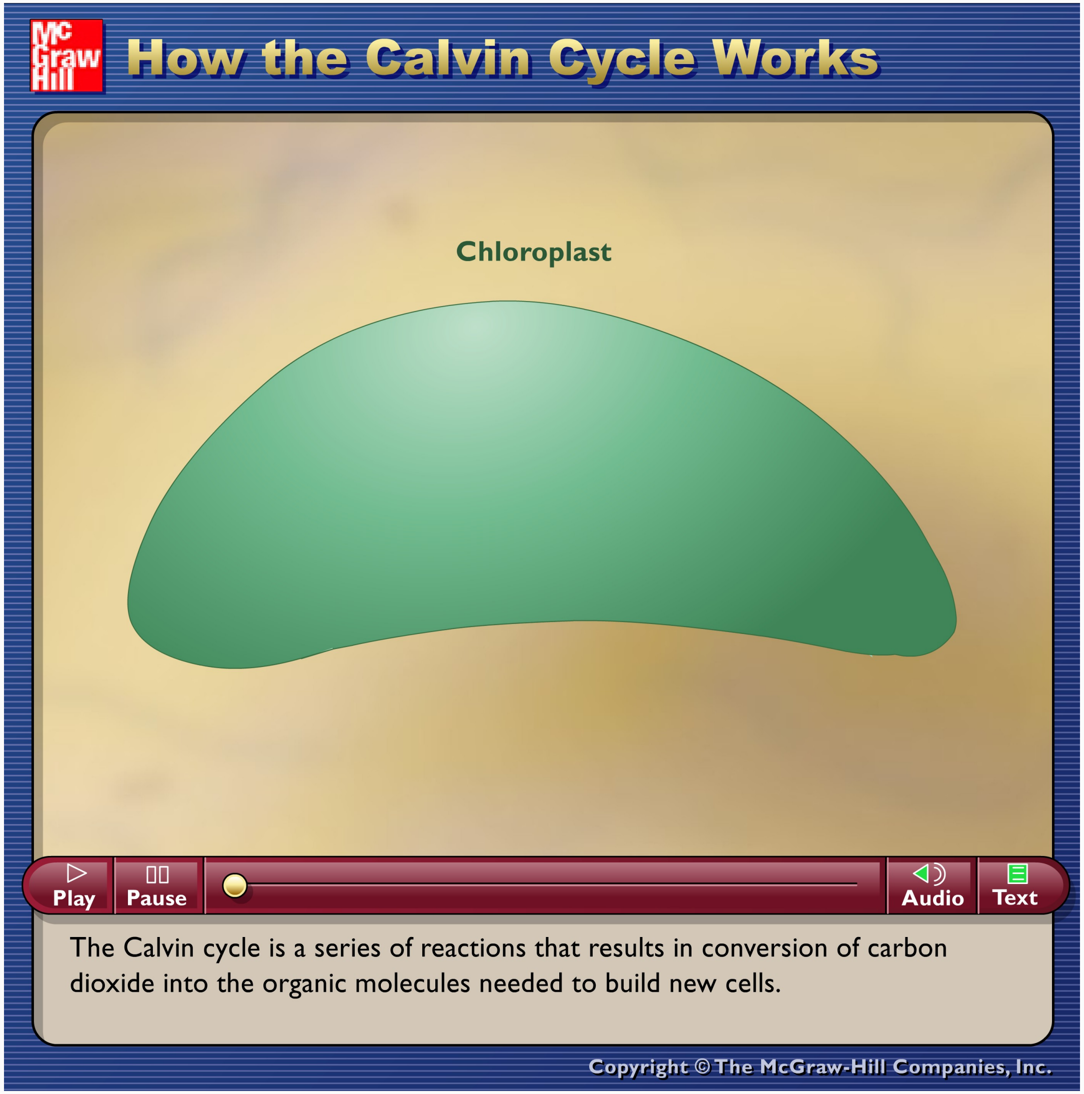


3. Regeneration of RuBP
   - PGAL (G3P) used to reform RuBP
   - Uses ATP

Calvin Cycle animation



Inputs and Outputs of the Calvin-Benson Cycle

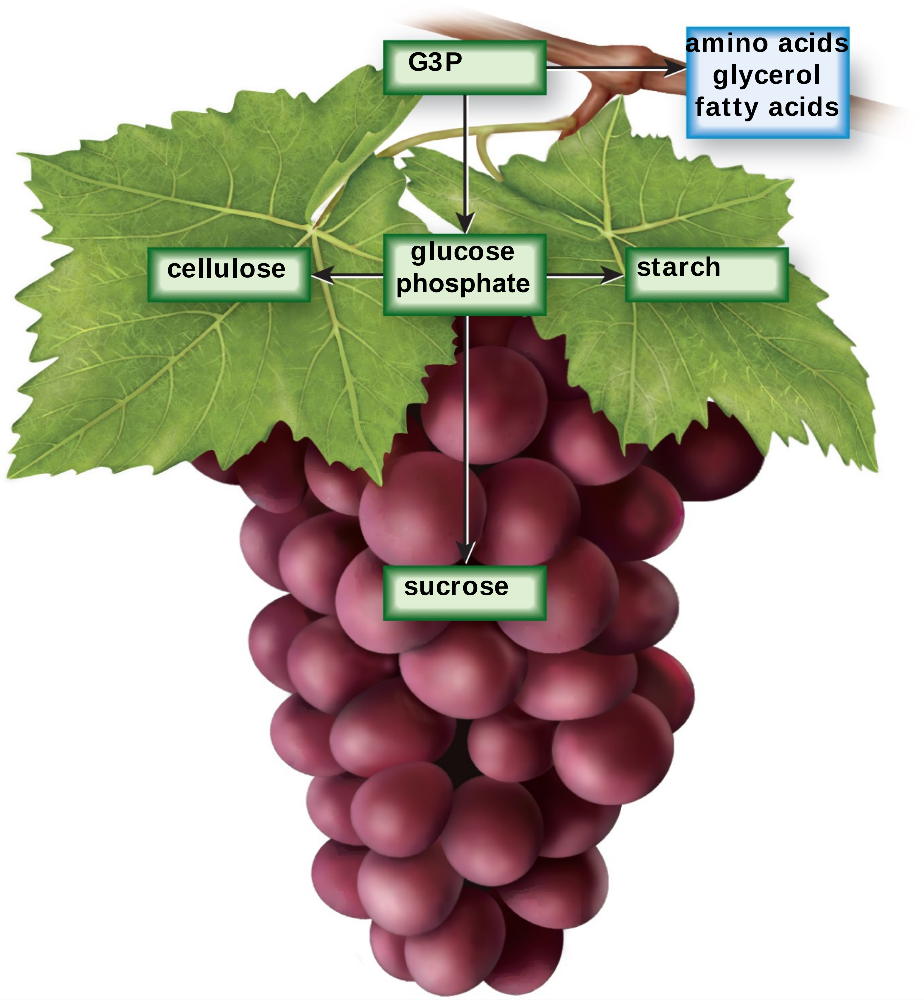


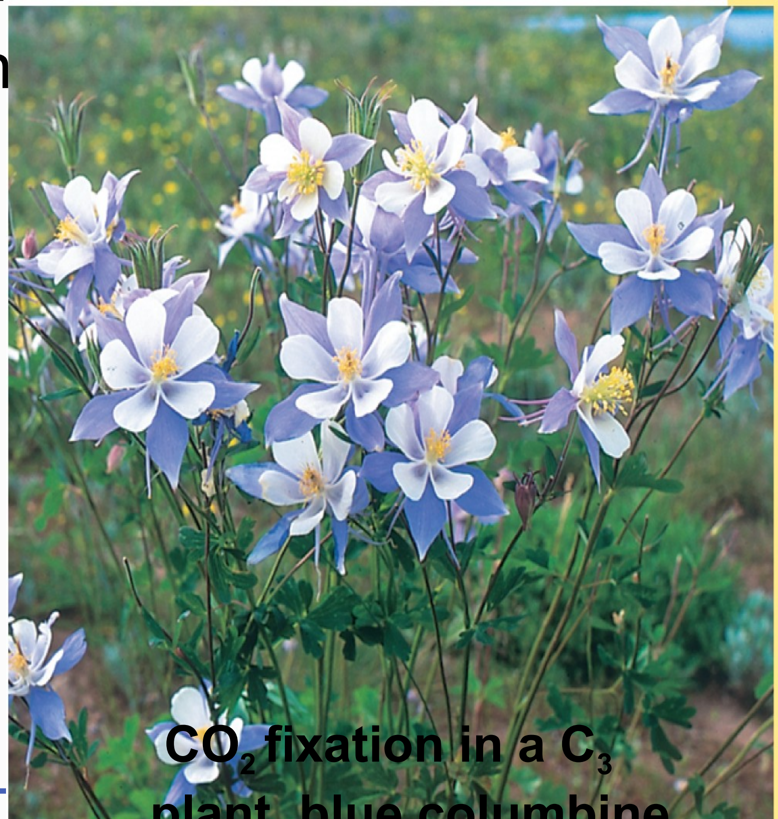
Figure 6.9 The fate of G3P (PGAL)

Other types of Photosynthesis

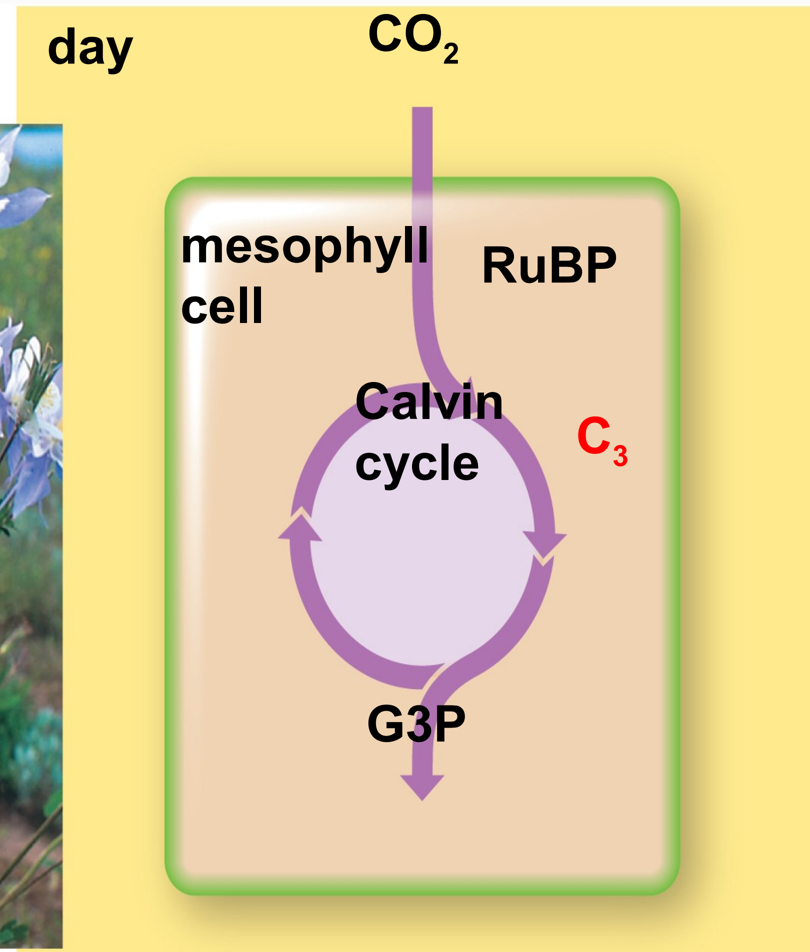
- Plants in different habitats photosynthesize differently
  - Moderate light and rainfall = C_3 plants

C_3 compound formed first in carbon fixation (like we saw)

All occurs in mesophyll cells

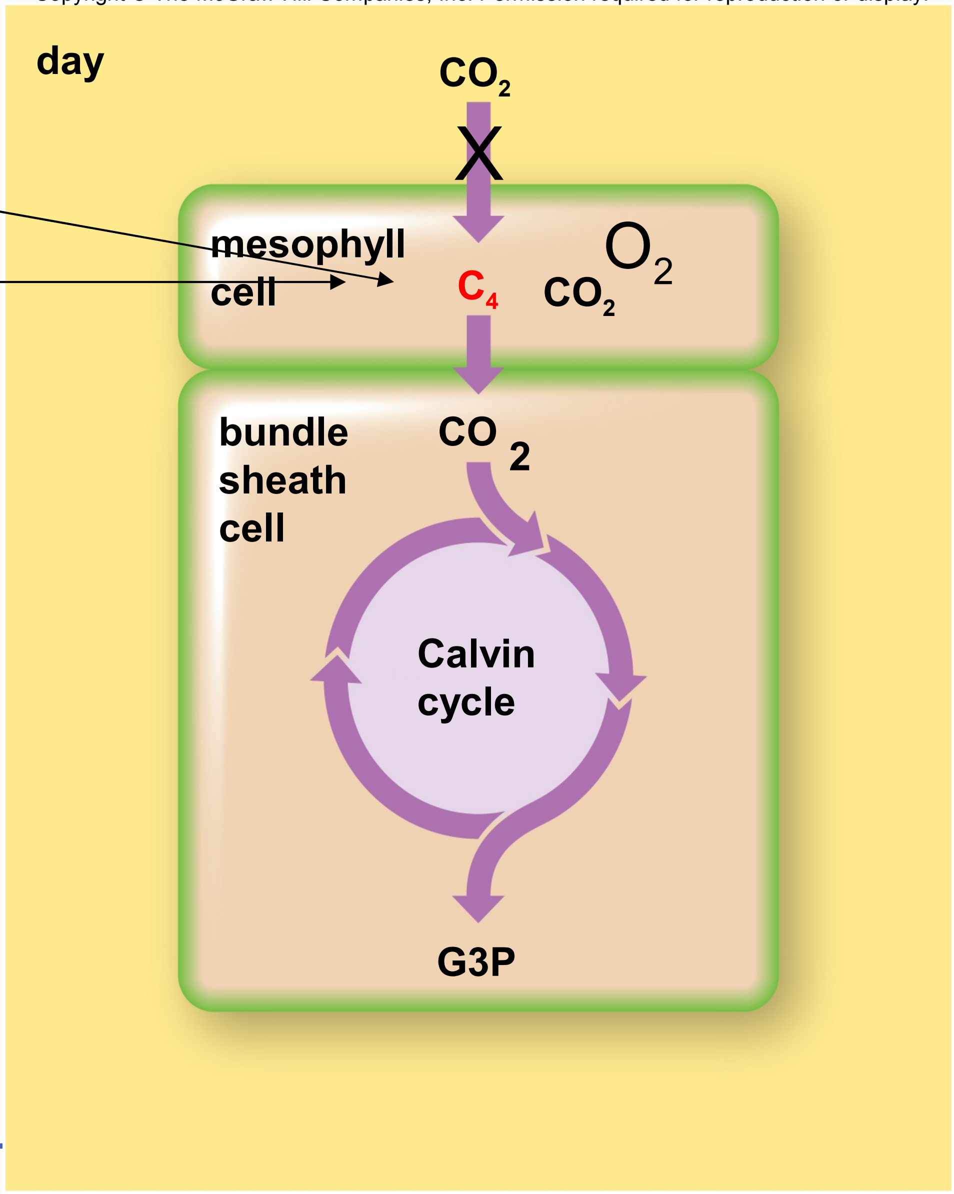


CO_2 fixation in a C_3 plant, blue columbine



Other types of Photosynthesis – preventing water loss!

- Hot and dry climates = C_4 plants
- To preserve water: Stomata closes – limits CO_2 uptake, water loss; traps O_2
- There's a problem!!!
- O_2 competes with CO_2 for rubisco – so less C_3 would be produced in Calvin Cycle if photosynthesis were the same as in C_3 plants (in the

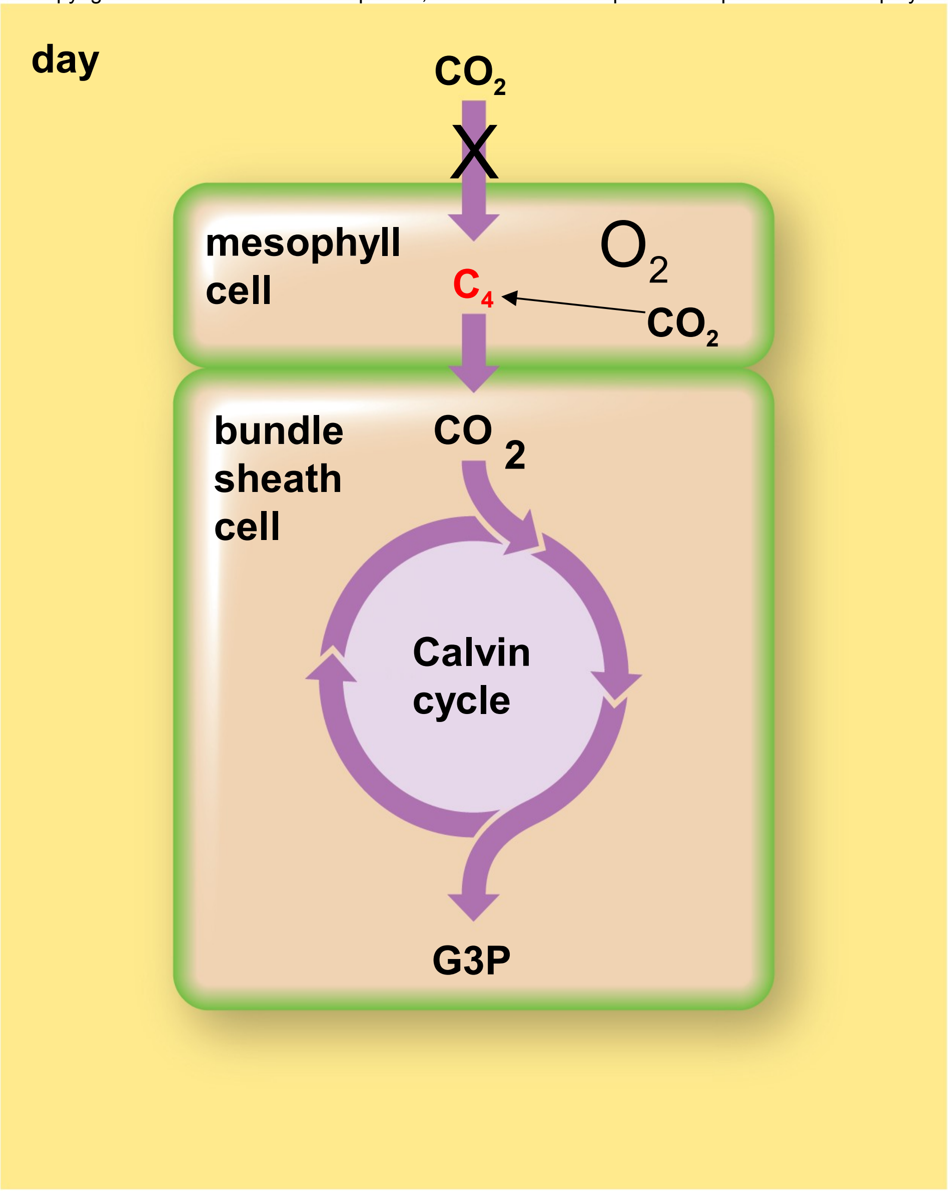


Other types of Photosynthesis – preventing water loss!

- C_4 plants do it differently!

- Rxns are divided by space! CO_2 is fixed in mesophyll cells FIRST!!!

- Fixed carbon then enters bundle sheath cells for Calvin cycle – separated from O_2



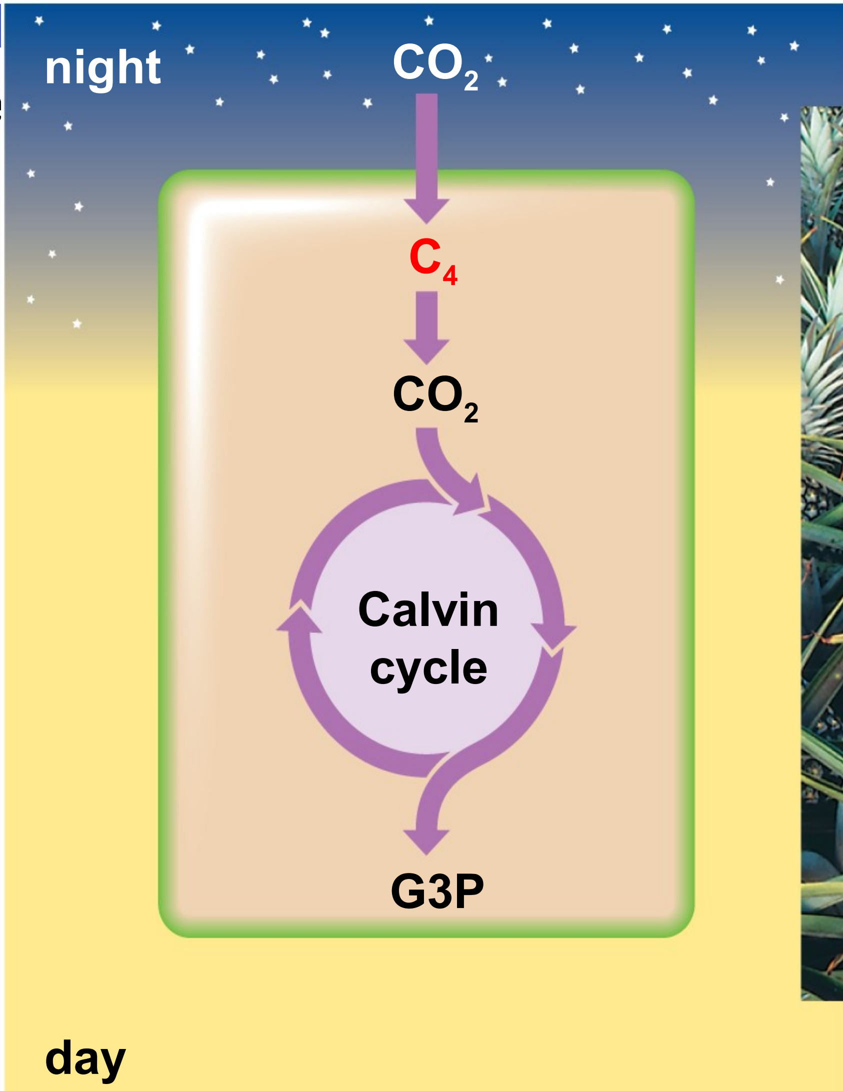
Differences between C_3 and C_4 plants – a summary

- C_3 plants
  - Calvin cycle occurs in the mesophyll cells
  - CO_2 is fixed as C_3
  - Advantageous in moderate weather

- C_4 plants
  - CO_2 is fixed in mesophyll cells as C_4
  - Calvin cycle occurs in bundle sheath cells, away from oxygen
  - Advantageous in hot, dry weather

Other types of photosynthesis

- Ve
  - ace
  - light



CO_2 fixation in a CAM plant, pineapple

The Spinach Battery!!!