Photosynthesis: all you need to know in one lecture.
Photosynthesis: overall reaction

\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2 \]

- **Sun's energy**
- **Carbon dioxide**
- **Water**
- **Chlorophyll**
- **Sugars**
- **Oxygen**
Leaf—Levels of Organization (1)

- Cuticle
- Epidermis
- Mesophyll
- Vascular bundle
  - Bundle sheath
- Stoma
Leaf—Levels of Organization (2)

- Chloroplasts
- Vacuole
- Nucleus
- Cell wall
- Outer membrane
- Inner membrane
- Granum
- Stroma
- Thylakoid
Electromagnetic Spectrum

Increasing energy

Increasing wavelength

0.001 nm 1 nm 10 nm 1000 nm 0.01 cm 1 cm 1 m 100 m

Gamma rays X rays UV light Infrared Radio waves

Visible light

400 nm 430 nm 500 nm 560 nm 600 nm 650 nm 740 nm
Chlorophyll is well-adapted to use Solar Energy.
Chlorophyll molecules embedded in a protein complex in the thylakoid membrane.

Chlorophyll $a$: $R = -\text{CH}_3$

Chlorophyll $b$: $R = -\text{CHO}$

Porphyrin head

Hydrocarbon tail

Granum
Carotenoids and Other Accessory Pigments

Oak leaf in summer

Oak leaf in autumn
The “green drop” of chlorophyll is minimized in most leaves.

http://www.photobiology.info/Gorton.html
Why are plants green?
**Light energy**

- **Resonance energy transfer**
- **Pigment molecules**
- **Antenna complex (in thylakoid membrane)**

**Reaction center**

**Special chlorophyll a molecules**

**Electron acceptor**
Chlorophyll and photons

http://click4biology.info/c4b/8/resp8.2.htm
Chlorophyll and photons: colors don’t matter.
The Z-scheme of the Light Reactions: An Energy Diagram

-2.0
-1.5
-1.0
-0.5
0
0.5
1.0
1.5
2.0

E_m (volts)

2 H_2O → 4 e^- + 4 H^+ (oxidizing)

O_2 + 4 H^+ → 4 e^- + 2 H_2O (reducing)

P680* → P700*

Pheo → PQ → cyt b → cyt f → PC

FeS → Fd → FNR

NADP^+ + e^- + H^+ → NADPH
Oxygenic photosynthetic electron transport has two aims: (1) pump protons, (2) reduce NADP.
The four protein complexes of photosynthetic electron transport are big and multi-peptide.
Two photosystems are required to both oxidize water and reduce NADP.
The photosynthetic light response.
The four possible fates of an absorbed photon.
Preventing damage from excess light

The Calvin Cycle
(i.e., the CO₂ fixation cycle; a.k.a., the “dark” reactions)

Figure 4.12
Rubisco

- Ribulose bisphosphate carboxylase oxygenase
- “Fixes” CO$_2$ & O$_2$
  - Fixing O$_2$ is a mistake
- Enzyme in Calvin Cycle
  - Catalyzes 1$^{st}$ step
- Most abundant protein on Earth
  - Often 25% of total leaf protein
- One of the slowest enzymes on Earth
Photorespiration

• When rubisco “fixes” O₂, not CO₂
• Lose previously-fixed C as CO₂
• Take up O₂
• Only occurs in light
• Expensive to repair the “damage”
• Occurs ca. 1 out of 4 reactions under today’s atmospheric [CO₂], but this rate decreases with increasing CO₂
• Rate increases with temperature
Photorespiration (PR)

rubisco

5-carbon + O₂ → 3-carbon compound + 2-carbon compound

↓ enters the Calvin cycle, becomes sugar

↓ enters the PR cycle; 1C lost as CO₂, 1C recovered; wastes energy
Types of photosynthesis

- **C3**
  - The majority of plants
  - High rates of photorespiration at today’s CO$_2$ level

- **C4**
  - Have a CO$_2$-concentrating mechanism (aka, CO$_2$ “pump”)
  - CO$_2$ first fixed by pepcase, then released and re-fixed by rubisco
  - Advantage in high light, high temperature, low CO$_2$, dry, saline
  - Many grasses and crops (e.g., corn, sorghum, millet, sugar cane)

- **CAM**
  - Have similar CO$_2$-concentrating mechanism as C4
  - Stomata open during night, closed in day
  - Advantage in arid (dry) climates
  - Many succulents (e.g., cacti, euphorbs, bromeliades, agaves)
Comparison of C₄ and CAM Plants

Mesophyll cell

Bundle-sheath cell

C₄ pathway

Calvin cycle

Glucose

C₄ plants

Night

Mesophyll cell

Day

CAM plants

CO₂

CO₂

CO₂
Photosynthetic response to CO₂

Ambient CO₂ concentration (ppm)

0 200 400 600 800 1000

Net CO₂ uptake (µmol m⁻² s⁻¹)

0 10 20 30 40 50 60

C3

C4

initial slope = carboxylation efficiency

X-intercept = CO₂ compensation point

CO₂ saturation
The photosynthetic temperature response.
Photorespiration ↑ with temperature, ↓ with CO$_2$.
To predicting effects of global environmental change on the biosphere: you must start with photosynthesis (PS)

- Human activities are:
  - Increasing atmospheric CO$_2$ ($\uparrow$ PS)
  - Increasing average ($\uparrow$ or $\downarrow$ PS) and extreme temperatures ($\downarrow$ PS)
  - Increasing nitrogen ($\uparrow$ PS)
  - Changing precipitation (drought $\downarrow$ PS; increased rain usually $\uparrow$ PS)
  - Increasing ground-level ozone ($\downarrow$ PS)