Lecture 10 – Photosynthesis

Whadaya mean, OOPS?! That stuff doesn’t grow on trees you know!

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In this lecture...

• Respiration vs. photosynthesis
• Electromagnetic spectrum
• Structure of chloroplasts
• Chlorophyll
• The light cycle
  – Linear flow
  – Cyclic flow
• The Calvin Cycle
Recycling Carbon

• Atomic carbon is recycled from plants to animals and back again
• This happens because cellular respiration and photosynthesis are opposite reactions

\[ \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{energy} \]

\[ 6\text{CO}_2 + 12\text{H}_2\text{O} + \text{energy} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{H}_2\text{O} + 6\text{O}_2 \]
Sunlight is the source of energy on Earth

Photosynthesis occurs in plants, algae, certain other protists, and some prokaryotes.

These organisms feed not only themselves but also most of the living world.
Why do photosynthesis?

• Photosynthesis creates glucose from carbon dioxide, water and light
• Plants need glucose to store energy and to build cellulose
• However, photosynthesis does not produce enough ATP for the cell’s purposes
• Plant cells also have mitochondria to produce ATP
Respiration vs. Photosynthesis

**Respiration**

Glucose $\rightarrow$ Energy + ATP + CO$_2$

Organisms that must consume other organisms to get their organic molecules are **heterotrophs**

**Photosynthesis**

Energy + Water + CO$_2$ $\rightarrow$ Glucose

Organisms that produce their own food are **autotrophs**
Respiration vs. Photosynthesis

\[
\text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 \rightarrow 6 \text{CO}_2 + 6 \text{H}_2\text{O} + \text{Energy}
\]

\[
\text{Energy} + 6 \text{CO}_2 + 6 \text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2
\]
First, we have to understand what light is

- Light is a form of electromagnetic energy, also called electromagnetic radiation
- Light is packaged into discrete units called **photons**
- Like other electromagnetic energy, photons travel in rhythmic waves
- **Wavelength** is the distance between crests of waves
- Wavelength determines the type of electromagnetic energy
The electromagnetic spectrum

The **electromagnetic spectrum** is the entire range of electromagnetic energy.
Where does photosynthesis happen?

Photosynthesis takes place in the chloroplasts.
Photosynthesis: The process

Chloroplasts split $\text{H}_2\text{O}$ into hydrogen and oxygen using light energy, incorporating the electrons of hydrogen into sugar molecules and releasing oxygen as a by-product.

Reactants:
- $6 \text{CO}_2$
- $12 \text{H}_2\text{O}$

Products:
- $\text{C}_6\text{H}_{12}\text{O}_6$
- $6 \text{H}_2\text{O}$
- $6 \text{O}_2$
What goes where in chloroplasts

Chloroplasts are solar-powered chemical factories

Chloroplasts contain thylakoid membranes

Thylakoid membranes contain photosystems

Photosystems contain light-harvesting complexes

Light-harvesting complexes surround reaction-center complexes

Reaction-center complexes have two special light-capturing chlorophyll molecules

There are two types of photosystems

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What goes where in chloroplasts

(a) How a photosystem harvests light

(b) Structure of photosystem II

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The two different photosystems

- Photosystem II
  - Functions first
  - Best absorbs light at 680nm
  - The reaction-center chlorophyll a is called P680
- Photosystem I
  - Best absorbs light at 700nm
  - The reaction-center chlorophyll a is called P700
  - Comes after PSII
What is chlorophyll?

- Chlorophyll is a pigment
- Pigments are substances that absorb visible light
- Different pigments absorb different wavelengths
- Wavelengths that are not absorbed are reflected/transmitted

Leaves appear green because chlorophyll reflects/transmits green light
What is chlorophyll?

• Chlorophyll $a$ is the main photosynthetic pigment
• Accessory pigments, such as chlorophyll $b$, broaden the light spectrum that can be used for photosynthesis
• Accessory pigments called carotenoids absorb excessive light that would damage chlorophyll
What is chlorophyll?

- An **absorption spectrum** is a graph plotting a pigment’s light absorption versus wavelength.

- The absorption spectrum of **chlorophyll a** suggests that violet-blue and red light work best for photosynthesis.

- An **action spectrum** profiles the relative effectiveness of different wavelengths of radiation in driving a process.
How does chlorophyll absorb light?

• When a pigment absorbs light, it goes from a ground state to an excited state, which is unstable.
• When excited electrons fall back to the ground state, photons are given off, an afterglow called fluorescence.
• If illuminated, an isolated solution of chlorophyll will fluoresce, giving off light and heat.
How does chlorophyll absorb light?

(a) Excitation of isolated chlorophyll molecule
(b) Fluorescence
Photosynthesis: The process

- Two parts:
  - The light cycle (the *photo* part)
  - The Calvin cycle (the *synthesis* part)
The Light Cycle

Begin: $\text{H}_2\text{O}$  NADP  ADP

End: $\text{O}_2$  NADPH  ATP

*Two possible routes for electron flow:*

**Linear**
The primary pathway
Involves both photosystems
Produces ATP and NADPH using light energy

**Cyclic**
Uses only photosystem I
Generates surplus ATP to satisfy the higher demand in the Calvin cycle

*Creates ATP and NADPH from light energy*
The Light Cycle – Linear Flow

- A photon hits an electron in a pigment and the excited electron is passed among pigment molecules until it hits P680.
- This excited electron from P680 is transferred to the primary electron acceptor.
  - P680\(^+\) is now missing an electron and is a strong oxidizing agent.

- A primary electron acceptor in the reaction center accepts excited electrons and is reduced as a result.
The Light Cycle – Linear Flow

• H₂O is split by enzymes, and the electrons are transferred from the hydrogen atoms to P680⁺, thus reducing it to back P680. We are oxidizing water!
• O₂ is released as a by-product of this reaction
The Light Cycle – Linear Flow

- The electron is transferred from PSII to PSI along an electron transport chain, causing the electron to lose energy in small steps.
- This loss of energy is coupled to pumping protons across the membrane, creating an electrochemical gradient.
- ATP is produced. This is called photophosphorylation – where photons are used to phosphorylate ADP to ATP.
The Light Cycle – Linear Flow
The Light Cycle – Cyclic Flow

- **Cyclic electron flow** uses only photosystem I and produces ATP, but not NADPH
- No oxygen is released
- Cyclic electron flow generates surplus ATP, satisfying the higher demand in the Calvin cycle
• Some organisms such as purple sulfur bacteria have PS I but not PS II
• Cyclic electron flow is thought to have evolved before linear electron flow
• Cyclic electron flow may protect cells from light-induced damage
Electron transport chains in mitochondria vs. chloroplasts

In mitochondria, protons are pumped to the intermembrane space and drive ATP synthesis as they diffuse back into the mitochondrial matrix.

In chloroplasts, protons are pumped into the thylakoid space and drive ATP synthesis as they diffuse back into the stroma.
Electron transport chains in mitochondria vs. chloroplasts
The Calvin Cycle

Creates glucose from ATP and NADPH

Begin:
3 CO$_2$
ATP
NADPH

End:
1 Glyceraldehyde-3-phosphate
ADP
NADP

The Calvin cycle is where carbon fixation takes place. Carbon fixation is the process of turning atmospheric carbon dioxide into glucose.

This is a light-independent reaction – it takes place without the direct input of light.

The Calvin cycle has three phases

Carbon fixation (catalyzed by rubisco)
Reduction
Regeneration of the CO$_2$ acceptor (RuBP)
The Calvin Cycle

For net synthesis of 1 G3P, the cycle must take place three times, fixing 3 molecules of CO$_2$. 
Figure 10.22

Light

Reactions:
Photosystem II
Electron transport chain
Photosystem I
Electron transport chain

Light

H₂O

CO₂

O₂

NADP⁺
ADP

ATP

NADPH

RuBP

3-Phosphoglycerate

Calvin Cycle

G3P

Starch (storage)

Sucrose (export)

Chloroplast

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The importance of photosynthesis

• The energy entering chloroplasts as sunlight gets stored as chemical energy in organic compounds
• Sugar made in the chloroplasts supplies chemical energy and carbon skeletons to synthesize the organic molecules of cells
• Plants store excess sugar as starch in structures such as roots, tubers, seeds, and fruits
• In addition to food production, photosynthesis produces the O$_2$ in our atmosphere
Vocabulary

• The electromagnetic spectrum
• Photons
• Chloroplast
• Chlorophyll
• Photosystems I and II
• Light cycle - cyclic flow vs linear flow
• Calvin cycle
Questions?