Overview: The Process That Feeds the Biosphere

- **Photosynthesis** is the process that converts solar energy into chemical energy
- Directly or indirectly, photosynthesis nourishes almost the entire living world
Slide 4

**Autotrophs** sustain themselves without eating anything derived from other organisms.

- Autotrophs are the *producers* of the biosphere, producing organic molecules from CO₂ and other inorganic molecules.
- Almost all plants are photoautotrophs, using the energy of sunlight to make organic molecules from H₂O and CO₂.

Slide 5

**Heterotrophs** obtain their organic material from other organisms.

- Heterotrophs are the *consumers* of the biosphere.
- Almost all heterotrophs, including humans, depend on photoautotrophs for food and O₂.

Slide 6

**Concept 10.1: Photosynthesis converts light energy to the chemical energy of food**

- __________ are the major site of photosynthesis.
- __________ are structurally similar to and likely evolved from photosynthetic bacteria.
- Photosynthesis can be summarized as the following equation:
  
  \[ 6\text{CO}_2 + 12\text{H}_2\text{O} + \text{Light energy} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 + 6\text{H}_2\text{O} \]

  How does this equation differ from cellular respiration?
Slide 7

What cells contain most of the chloroplast?

________________________

________________________

________________________

________________________

________________________

________________________

________________________

________________________

________________________

Slide 8

Identify the following on the image:

A. Connected sacs in the chloroplast that contain chlorophyll

B. The "stacks" of thylakoids

C. Dense fluid that fills the chloroplast

________________________

________________________

________________________

________________________

________________________

________________________

________________________

________________________

________________________

Slide 9

The Splitting of Water

- Chloroplasts split H₂O into hydrogen and oxygen, incorporating the electrons of hydrogen into sugar molecules

- Photosynthesis is a redox process in which _______ is oxidized and _______ is reduced

6 CO₂ + 12 H₂O + Light energy → C₆H₁₂O₆ + 6 O₂ + 6 H₂O

________________________

________________________

________________________

________________________

________________________

________________________

________________________

________________________

________________________
The Two Stages of Photosynthesis: A Preview

- Photosynthesis consists of the **light reactions** (the photo part) and **Calvin cycle** (the synthesis part)
- The light reactions (in the thylakoids):
  - Split $H_2O$
  - Release $O_2$
  - Reduce $NADP^+$ to $NADPH$
  - Generate ATP from ADP by photophosphorylation

The Calvin cycle (in the stroma) forms sugar from $CO_2$, using ATP and NADPH
- The Calvin cycle begins with **carbon fixation**, incorporating $CO_2$ into organic molecules
Slide 13

THYLAKOID SPACE
(INTerior OF THYLAKOID)

STROMA

e–
Pigment
molecules

Photon
Transfer
of energy

Special pair of chlorophyll $a$
molecules

Thylakoid membrane

Photosystem

Primary electron acceptor

Reaction-center complex

Light-harvesting complexes

• A photosystem
  • 1) reaction-center complex (a type of protein complex)
  • 2) light-harvesting complexes
The light-harvesting complexes (pigment molecules bound to proteins) funnel the energy of photons to the reaction center

Copyright © 2008 Pearson Education, Inc., publishing as Pearson Benjamin Cummings

Slide 14

• A primary electron acceptor in the reaction center accepts an excited electron from chlorophyll $a$

• Solar-powered transfer of an electron from a chlorophyll $a$ molecule to the primary electron acceptor is the first step of the light reactions

Copyright © 2008 Pearson Education, Inc., publishing as Pearson Benjamin Cummings

Slide 15

• There are two types of photosystems in the thylakoid membrane

• Photosystem II (PS II) functions first (the numbers reflect order of discovery) and is best at absorbing a wavelength of 680 nm

• The reaction-center chlorophyll $a$ of PS II is called P680

• Photosystem I (PS I) is best at absorbing a wavelength of 700 nm

• The reaction-center chlorophyll $a$ of PS I is called P700

Copyright © 2008 Pearson Education, Inc., publishing as Pearson Benjamin Cummings
A Comparison of Chemiosmosis in Chloroplasts and Mitochondria

- Chloroplasts and mitochondria generate ATP by chemiosmosis, but use different sources of energy.
- Mitochondria transfer chemical energy from food to ATP; chloroplasts transform light energy into the chemical energy of ATP.
- Spatial organization of chemiosmosis differs between chloroplasts and mitochondria but also shows similarities.

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.

---

**Key**

- **Mitochondrion**
- **CHLOROPLAST\nSTRUCTURE**
- **Intermembrane space**
- **Inner membrane**
- **Electron transport chain**
- **H+ Diffusion**
- **Matrix**
- **Higher [H+]**
- **Lower [H+]**
- **Stroma**
- **ATP synthase**
- **ADP + Pi**
- **Thylakoid membrane**
- **Thylakoid space**
- **Electron transport chain**
- **Diffusion**
- **ATP synthase**
- **Matrix**
- **ADP + Pi**
- **Thylakoid membrane**
- **Thylakoid space**
- **Electron transport chain**
- **Diffusion**
Slide 19

- ATP and NADPH are produced on the side facing the stroma, where the Calvin cycle takes place.
- In summary, light reactions generate ATP and increase the potential energy of electrons by moving them from H₂O to NADPH.

Slide 20

Slide 21

Concept 10.3: The Calvin cycle uses ATP and NADPH to convert CO₂ to sugar

- The Calvin cycle, like the citric acid cycle, regenerates its starting material after molecules enter and leave the cycle.
- The cycle builds sugar from smaller molecules by using ATP and the reducing power of electrons carried by NADPH.
Slide 22

- Carbon enters the cycle as CO₂ and leaves as a sugar named \textit{glyceraldehyde-3-phospate} (G3P)
- For net synthesis of 1 G3P, the cycle must take place three times, fixing 3 molecules of CO₂
- The Calvin cycle has three phases:
  - \textit{Carbon fixation} (catalyzed by \textit{rubisco})
  - \textit{Reduction}
  - \textit{Regeneration of the CO₂ acceptor (RuBP)}

---

Slide 23

Concept 10.4: Alternative mechanisms of carbon fixation have evolved in hot, arid climates

- Dehydration is a problem for plants, sometimes requiring trade-offs with other metabolic processes, especially photosynthesis
- On hot, dry days, plants close stomata, which conserves H₂O but also limits photosynthesis
- The closing of stomata reduces access to CO₂ and causes O₂ to build up
- These conditions favor a seemingly wasteful process called photorespiration

---

Slide 24

Photorespiration: An Evolutionary Relic?

- In most plants (C₃ plants), initial fixation of CO₂, via \textit{rubisco}, forms a three-carbon compound
- In \textit{photorespiration}, \textit{rubisco} adds O₂ instead of CO₂ in the Calvin cycle
- Photorespiration consumes O₂ and organic fuel and releases CO₂ without producing ATP or sugar
Slide 25

• Photorespiration may be an evolutionary relic because rubisco first evolved at a time when the atmosphere had far less O₂ and more CO₂
• Photorespiration limits damaging products of light reactions that build up in the absence of the Calvin cycle
• In many plants, photorespiration is a problem because on a hot, dry day it can drain as much as 50% of the carbon fixed by the Calvin cycle

Slide 26

C₄ Plants

• C₄ plants minimize the cost of photorespiration by incorporating CO₂ into four-carbon compounds in mesophyll cells
• This step requires the enzyme PEP carboxylase
• PEP carboxylase has a higher affinity for CO₂ than rubisco does; it can fix CO₂ even when CO₂ concentrations are low
• These four-carbon compounds are exported to bundle-sheath cells, where they release CO₂ that is then used in the Calvin cycle

Slide 27

CAM Plants

• Some plants, including succulents, use crassulacean acid metabolism (CAM) to fix carbon
• CAM plants open their stomata at night, incorporating CO₂ into organic acids
• Stomata close during the day, and CO₂ is released from organic acids and used in the Calvin cycle
Slide 28

**Fig. 10-20**

- Sugarcane
- Mesophyll cell
- CO2 incorporation into four-carbon organic acids
  - CO2 is released to the Calvin cycle

- Pineapple
- CAM sugar cycle
  - Organic acid release
  - CO2 incorporated into four-carbon organic acids

 Slide 29

**The Importance of Photosynthesis: A Review**

- 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 O₂ in our atmosphere

Copyright © 2008 Pearson Education, Inc., publishing as Pearson Benjamin Cummings