Photosynthesis

Plants also use ________________ for energy production

How do plants obtain glucose?

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

Use of ________________ produce glucose

______________ used for glucose production

Process gives off ________

Produced glucose can be used for glycolysis, TCA cycle, e\text{-} tranport/ox. phos.
Photosynthesis

**Chloroplast** - organelle in plant cells
- inner & outer membrane
- thylakoid
- grana - stack of thylakoids
- stroma - similar to mitochondrial matrix

**Diagram:**
- thylakoid space
- thylakoid lumen
Photosynthesis

2 parts to photosynthesis

1. **Light reactions** – excitation of ________________________________
   - energy in excited e\(^{-}\) used for ________________________________
   - also splits H\(_2\)O giving off _____________
   - takes place in thylakoid
   - very similar to ________________________________

2. **Dark reactions** – does not require _____________
   - use of ATP and NADH to fix ________________________________
   - takes place in stroma
Photosynthesis

Other photosynthetic organisms besides land plants

- ________________
- ____________ (blue-green algae)
- ________________ (green and purple sulfur bacteria)

- use ________________
- release ________________
- red & brown algae (_____________)

Purple sulfur bacteria from Great Salt Lake
Photosynthesis

Chlorophyll

- absorbs light energy to ________________________________

- ________________ of hemoglobin, myoglobin, and cytochromes

- has bound ________________ instead of Fe

- __________________ acts as thylakoid membrane anchor

- two types of chlorophyll (a, b) ________________________________

Y is —CH$_3$ in chlorophyll $a$
Y is —CHO in chlorophyll $b$
Y is —CH$_3$ in bacteriochlorophyll $a$

(and highlighted bond is saturated)
Photosynthesis
Chlorophyll

Why are plants green?
- Chl $a$ & Chl $b$ absorb light in the _________________ and _________________ range of visible light.

- Reflect _________________ lengths

- Having both Chl’s allows for increased amount of __________

________________________

[Diagram showing absorption spectra of Chlorophyll $a$ and Chlorophyll $b$.]
Photosynthesis
Accessory Pigments

- Absorb light ______________________
- _______________________ to chlorophyll

Phycocyanin

Phycoerythrin

Carotenoids

Lutein (xanthophyll)

Cryptoxanthin

Zeaxanthin

Absorption spectrum of various accessory pigments and chlorophylls compared to the solar spectrum.
Photosynthesis
Light Reactions
- light excited $e^-$ from chlorophyll are passed from ________________
- process moves ________________
- $H^+$ used to ________________
- NADP$^+$ reduced to NADPH
Photosynthesis
Light Reactions

**Z scheme** - __________________ light reactions for reduction of NADP⁺

**PS II** - chlorophyll absorbs ______________________
- electrons become excited, _______________________
- e⁻ passed to ________________________________, Chl with out Mg²⁺
- passed through intermediates to ________________ (PQ)
- PQ acts similar to CoQ
- freely moves in thylakoid membrane
- transfers e⁻ to a complex of cytochromes
Photosynthesis
Light Reactions

Oxygen generation

- $e^-$ donated by Chl $P_{680}$

- $H_2O$ is split into

- $e^-$ transferred to Chl $P_{680}$

- requires 2 $H_2O$ for _______

- $H^+$ deposited into thylakoid lumen
Photosynthesis
Light Reactions

Cytochrome $b_6$-$f$ complex

- accepts $e^-$ __________________
- utilizes cytochrome proteins and Fe-S proteins
- contains a ___________________________ complex III of $e^-$ transport

- $e^-$ transferred to __________ (PC)
- Cu ion acts as $e^-$ carrier in PC
- PC not in membrane
- _______________ stroma to thylakoid lumen
Photosynthesis
Light Reactions

**PS I** - chlorophyll absorbs ________________________________

- electrons passed from PC become excited, ____________________________

- $e^-$ passed ________________, membrane bound ferredoxins (Fe-S proteins)

- $e^-$ passed to ____________________________

- $e^-$ passed to enzyme: __________

- NADP$^+$ reduced to NADPH

- z scheme complete
Photosynthesis

Light Reactions

ATP Production (photophosphorylation)

$H^+$ gradient generated

- $H^+$ from ________________________
- cytochrome complex ________________________

$H^+$ are used by chloroplast ATP synthase

[Diagram of photosynthesis and ATP production]
Photosynthesis
Light Reactions

Cyclic Photophosphorylation

- PS I can cycle

- __________________________ thylakoid lumen

- H⁺ used for ATP synthesis

- ________________ not produced

- used when ________________

- ________________ to accept e⁻ from PS I

Light Reactions
http://www.youtube.com/watch?v=hj_WKgnL6MI
Photosynthesis
Dark Reactions

- ___________________________ , but do not necessarily occur at night
- _____________________________ and fixes it into glucose

- glucose is put into ______________________________:

  Sucrose: - _____________________________
  - __________ bond
  - sugarcane
  - sugar beets

  Starch: - glucose polymer
  - $\alpha$-1,4 bond, ______
  - $\alpha$-1,6 bond, ______
  - most other plants
Photosynthesis
Dark Reactions

Cellulose:
- ____________________________
  - ___________________ bond
  - used as structural molecule
  - major component of ________________

- animals lack enzyme cellulase to ________________
- termites and grazing animal digestive tracts contain ___________________________

[Diagram: Repeating disaccharide in cellulose (β-cellobiose)]
Photosynthesis

Dark Reactions

Calvin Cycle: name of dark reactions

- American chemist

Melvin Ellis Calvin
(1911 - 1997)

- worked at UC, Berkeley

- used radioactive $^{14}$CO$_2$ to trace path to glucose

- used green algae Chlorella

- Nobel Prize in Chemistry, 1961
Photosynthesis

Calvin Cycle

Step 1

- _________________ with ribulose 1,5-bisphosphate (RuBP)

- unstable intermediate

- splits into _________________
RuBisCO: carbon fixation during photosynthesis

- a polymer of ________________:
  8 large subunits - ________________
  8 small subunits - ________________

- most abundant protein on earth
  - ________________ total leaf protein
  - plants fix ________________ of CO₂/year
  - ________________ of RuBisCO needed

- found in stroma of chloroplast
Photosynthesis
Calvin Cycle

Step 2: _______________________
- uses ATP
- phosphorylates 3-PG at C_1

Step 3: _______________________
- uses NADPH
- phosphate lost at C_1
- converted to aldehyde

Where does ATP and NADPH come from?
Photosynthesis
Calvin Cycle
Production of 6 carbon sugars
- reactions 4 - 8 same as

______________

Step 4: G3P isomerized __________

Step 5: G3P and DHAP combined to form _______________________

Step 6: F-1,6-BP converted to __________  

Step 7: F6P isomerized to __________  

Step 8: G6P converted __________
Photosynthesis
Calvin Cycle

Remaining rxns to regenerate

ATP required for last reaction:
Ru-5-P to Ru-1,5-P
Photosynthesis

Photosynthesis as a whole is:

\[ 6 \text{CO}_2 + 18 \text{ATP} + 12 \text{NADPH} + 12 \text{H}^+ + 12 \text{H}_2\text{O} \rightarrow \]

Glucose + 12 \text{NADP}^+ + 18 \text{ADP} + 18 \text{P}_i \]
**Photosynthesis**

**C₃ photosynthesis** - _______________ (3- phosphoglycerate, Calvin cycle) in the fixing of CO₂
- most plants use C₃ photosynthesis

**C₄ photosynthesis** - _______________ in the fixing of CO₂
- corn, many tropical plants

- capable of fixing CO₂
- C₄ plants live in hot environments
- keep pores for air exchange ______________
- take in ______________
Photosynthesis

**C₄ photosynthesis** - use of 4 carbon compounds in the fixing of CO₂

- CO₂ fixation and Calvin Cycle ____________________________

- cells near ____________________________

- CO₂ moved to cells ____________________________

- CO₂ released, ____________________________
Photosynthesis

**C₄ photosynthesis** - use of 4 carbon compounds in the fixing of CO₂
- CO₂ is fixed by combining 
- forms 
- oxaloacetate reduced 
- malate transported 
- malate oxidized 
- CO₂ reacts with RuBisCO in Calvin cycle
- pyruvate transported back to 
- phosphorylated and reacts with CO₂
Photosynthesis

**CAM photosynthesis** - photosynthesis carried out ______________________
- uses same CO\(_2\) fixing method ________________
- fixes CO\(_2\) ____________________________ and stores ________________
- in daytime, _____________________________, used in Calvin Cycle
- does not use separate cells for ____________________________

*Crassulacean acid metabolism*

- plants can keep gas exchange __________

- less H\(_2\)O loss
Photosynthesis

Comparison of photosynthetic carbon fixation
Photosynthesis

Evolutionary implications of photosynthesis

- Early earth atmosphere predominantly ____________________________
- no ______________
- some of the first life on earth was ____________________________
- fixed CO\textsubscript{2} and released O\textsubscript{2}
- allowed for O\textsubscript{2} based life forms to evolve

- low amount of ____________
  __________________

- purple-sulfur bacteria use _________________

- release S, not O\textsubscript{2}

- life would be very different!!