CONCEPT 3 – ENERGY AND METABOLISM- Photosynthesis PART2

1. Photosynthesis $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$
   a. Photosynthetic organisms capture free energy present in sunlight and use water and carbon dioxide to make carbon products and free oxygen.
   b. Light-dependent reactions- photophosphorylation
      (1) Photosystems I and II (chlorophyll and proteins) are embedded in the internal membranes of chloroplasts (thylakoids of the grana). They pass electrons through an electron transport chain (ETC). When electrons are passed they allow hydrogen ions (protons) across the thykaloid membrane. The formation of the proton gradient powers the process of ATP synthesis to add a phosphate ADP to ATP (chemiosmosis).
      (2) Electrons are passed to NADP+ to make NADPH (electron carrier)
      (3) H_2O is used and O_2 released as by-product
      (4) Red and blue light works best (green is reflected typically)
      (5) Energy converted from sun into chemical energy of ATP and NADPH to be used in building of sugar (Calvin Cycle)
   c. Light-independent reactions- Calvin Cycle
      (1) carbon fixation occurs (carbons of CO_2 used to make sugar)
      (2) occurs in stroma of chloroplasts
      (3) ATP and NADPH generated by light-dependent reactions are used to assemble glucose

Vocabulary

absorption spectrum
acetyl coA
anabolism
anaerobic metabolism
ATP
ATP synthase
autotroph
Calvin cycle
cellular respiration
chemiosmosis
chlorophyll
chloroplast
citric acid/Krebs cycle
electron transport chain
FAD/$FADH_2$
feedback inhibition
fermentation
glycolysis
light dependent reactions
light independent reactions
metabolic pathway
mitochondrion
NAD/NADH
NADP/NADPH
oxidative phosphorylation
photolysis
photosynthesis
photosystem I
photosystem II
pyruvate
stroma
substrate-level phosphorylation
thylakoid membrane

Thinking Questions

1. In the process of photosynthesis, carbon dioxide and water are both reactants.
   a. Describe the journey of a single hydrogen atom from water in photosynthesis.

water split ---> H+ (PSII) → gradient → through ATP synthase (stroma) → may be attached to NADP+ → NADPH → Calvin Cycle

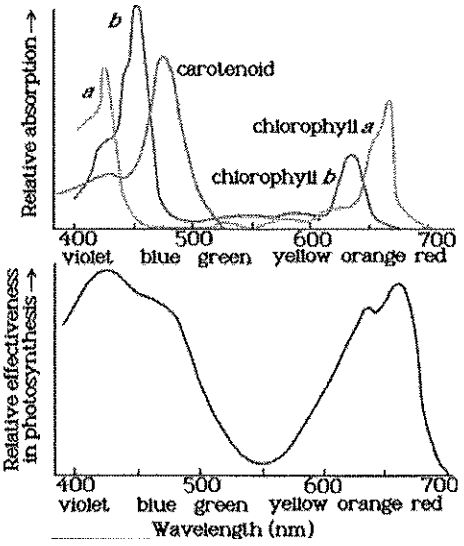
   b. Describe the journey of a single oxygen atom from water in photosynthesis.

water split ---> O_2 formed as waste product

   c. Describe the journey of a carbon dioxide molecule in photosynthesis.

CO_2 used in the Calvin Cycle to form glucose (or used to form molecules to drive Calvin Cycle)

2. The figures to the right display the absorption range for several different pigments found in plants (top) and the rate of photosynthesis at varying conditions of wavelength in one plant species (bottom):



   a. What color and wavelength of light is reflected by the plant species tested? How do you know?

Color reflected = green-yellow
very little absorption in 500-600 nm

   b. What wavelength(s) increase the rate of photosynthesis in the plant species tested? What pigment does this correspond to? How do you know?

- 425 nm and 675 nm
- Chlorophyll a - absorbs light in those ranges

Photosynthesis: You Otter Be Able To...

1. Describe the structure of a chloroplast

- double membrane & fluid-filled interior (stroma)
- thylakoid sacs embedded w/ pigment molecules and electron transport chain

2. Trace the movement of electrons in linear (non-cyclic) electron flow (electron transport chain)

Light → H_2O (PSII) ⇢ e^- ⇢ Light → PSI ⇢ e^- + NADP+ + H+ (stroma) ⇒ NADPH → Calvin Cycle

3. Explain how the electron transport chain and ATP synthase work together to make ATP.

electrons are passed through ETC which allow H+ to cross into thylakoid space and build H+ gradient. H+ move across membrane through ATP synthase to form ATP.

4. Describe how light energy is used to drive photosynthesis.

Light energy strikes PSII & PSI which excite electrons to move through ETC.

5. Some people believe that the oxygen gas we breathe is formed during photosynthesis when the carbon is removed from a carbon dioxide molecule. Correct this misconception by explaining what really happens.

- Oxygen on CO_2 molecules is used to build glucose in Calvin Cycle
- Oxygen on H_2O is split to form O_2.

6. Trace the movement of electrons in cyclic electron flow. Would the plant still get the same products? (ATP, NADPH, glucose)

H_2O ⇢ e^- PSII ⇢ e^- (PSI) ⇢ back to PSII

Products:
- ATP
- no NADPH

7. Describe the role of ATP and NADPH in the Calvin cycle

- ATP provides the chemical energy to ultimately form the bonds of glucose
- NADPH - provides electrons to molecules of the Calvin Cycle

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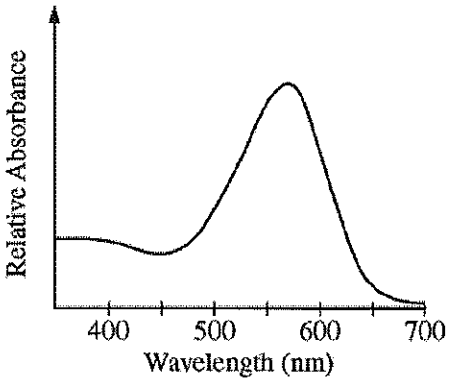
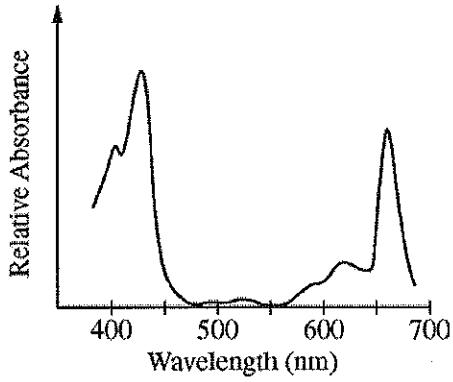
Question 2



Graph I



Graph II

Color	Wavelength (nm)
Violet	380–450
Blue	450–475
Cyan	475–495
Green	495–570
Yellow	570–590
Orange	590–620
Red	620–750

An absorption spectrum indicates the relative amount of light absorbed across a range of wavelengths. The graphs above represent the absorption spectra of individual pigments isolated from two different organisms. One of the pigments is chlorophyll *a*, commonly found in green plants. The other pigment is bacteriorhodopsin, commonly found in purple photosynthetic bacteria. The table above shows the approximate ranges of wavelengths of different colors in the visible light spectrum.

(a) **Identify** the pigment (chlorophyll *a* or bacteriorhodopsin) used to generate the absorption spectrum in each of the graphs above. **Explain** and **justify** your answer. (**3 points maximum**)

1 point per box
Identify BOTH pigments: Graph 1 = bacteriorhodopsin AND graph 2 = chlorophyll *a*
Explain that an organism containing bacteriorhodopsin appears purple because the pigment absorbs light in the green range of the light spectrum and/or reflects violet or red and blue light. The reflected red and blue light appears purple.
Explain that an organism containing chlorophyll *a* appears green because the pigment absorbs light in the red and blue ranges of the light spectrum and/or reflects green light.

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Question 2 (continued)

(b) In an experiment, identical organisms containing the pigment from Graph II as the predominant light-capturing pigment are separated into three groups. The organisms in each group are illuminated with light of a single wavelength (650 nm for the first group, 550 nm for the second group, and 430 nm for the third group). The three light sources are of equal intensity, and all organisms are illuminated for equal lengths of time. **Predict** the relative rate of photosynthesis in each of the three groups. **Justify** your predictions. (**5 points maximum**)

Wavelength (Group)	Prediction (**1 point each box**)	Justification (**1 point each box**)
650 nm (1^{st} Group)	Intermediate rate	An intermediate level of absorption occurs at 650 nm (compared to 430 nm and 550 nm); *therefore*, an intermediate amount of energy is available to drive photosynthesis.
550 nm (2^{nd} Group)	Lowest rate	The lowest level of absorption occurs at 550 nm; *therefore*, the least amount of energy is available to drive photosynthesis.
430 nm (3^{rd} Group)	Highest rate	The highest level of absorption occurs at 430 nm; *therefore*, the greatest amount of energy is available to drive photosynthesis.

NOTE: A student who combines two groups (e.g., "the 650 nm and 430 nm groups have higher rates of photosynthesis compared to the 550 nm group") can earn a maximum of 4 points: up to 2 points for the prediction and up to 2 points for the justification.

(c) Bacteriorhodopsin has been found in aquatic organisms whose ancestors existed before the ancestors of plants evolved in the same environment. **Propose** a possible evolutionary history of plants that could have resulted in a predominant photosynthetic system that uses only some of the colors of the visible light spectrum. (**1 point per box; 2 points maximum**)

Proposal that includes an environmental selective pressure: • Green light was being absorbed by aquatic organisms using bacteriorhodopsin. • Unabsorbed wavelengths of light were available resources that organisms could exploit. • Absorbing visible light at all wavelengths may provide too much energy to the organism. • Absorbing light from ultraviolet wavelengths (shorter wavelengths = higher energy) could cause damage to the organism. • Absorbing light with longer wavelengths may not provide sufficient energy for the organism.
Appropriate reasoning to support the proposal: • Natural selection favored organisms that rely on pigments that absorb available wavelengths of light. • Endosymbiosis: chloroplasts evolved from cyanobacteria with pigments that used only certain wavelengths. • Genetic drift eliminated pigments that absorbed certain wavelengths of light. • Mutation(s) altered the pigment(s) used by organism.