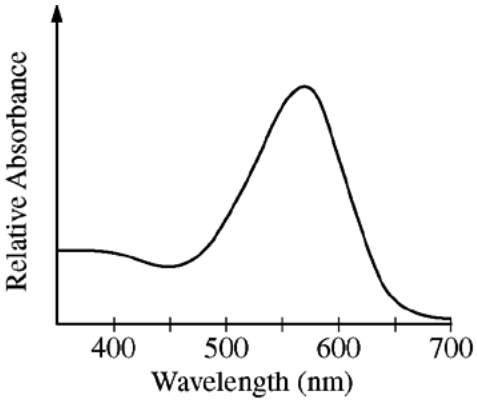
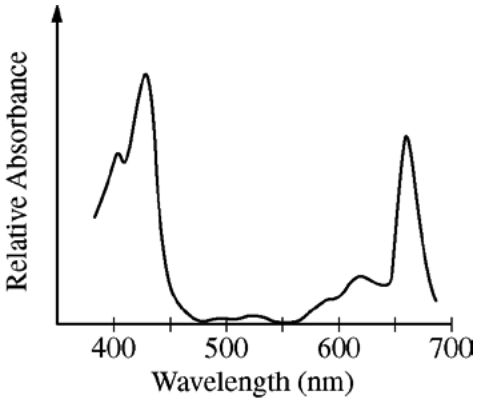
AP® BIOLOGY
2013 SCORING GUIDELINES

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.

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.

2A1

ANSWER PAGE FOR QUESTION 2

(a) In graph I bacteriorhodopsin is used to generate the absorbtion spectrum. This is known because Graph I shows a relatively low absorbtion rate for the color violet which is wavelength 380-450. Bacteriorhodopsin is usually found in purple photosynthetic bacteria and since the organism is purple, then it reflects rather than absorbs purple light. Graph II shows the absorbtion spectrum for chlorophyll a because it shows a low level of absorbtion of wavelengths 490-650 which correlates with the wavelength of green light (495-570). Chlorophyll a is found in green plants which means that green light would not be absorbed it would be reflected. Therefore, Graph II would represent chlorophyll a due to its low absorbtion of green light.

(b) The second group of organisms illuminated by 550nm light will have the lowest level of photosynthesis. This is because the main light-capturing pigment has a low absorbance of light in 550nm. Photosynthesis will be slow because the photosystems will not be able to capture enough light to excite the electrons and produce ATP and NADPH, the products of the light dependent reaction. The first group of organisms illuminated by 650nm will have a higher rate of photosynthesis than the second group

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but lower than the third group. The absorbtion spectrum of the predominant light-capturing pigment absorbs more light at 650 nm than at 550 nm. The organisms will be able to absorb more light than the second group and be able to send more NADPH and ATP from the light-dependant reactions to the light-independant reactions, also known as the Calvin Cycle. The third group that is illuminated by 430nm will have the highest rate of photosynthesis because 430nm light is absorbed relatively easier than the other two wavelengths of light. The organisms in the third group will be able to absorb more light and therefore create more NADPH and ATP which will then cause more products of the Calvin cycle to form. The third group of organisms will also produce the ~~most~~ amount of oxygen.

(e) In an aquatic environment a plant would have access to mostly blue and cyan colors of light of around 450-495 nm wavelength. If the plant contained many pigments that absorbed red light, that ~~is barely~~ a plant could rarely gain access to,

2A3

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the plant would not be able to absorb enough light to undergo photosynthesis. The plant would most likely not be able to reproduce ~~be~~fore it died. But if a plant had many photo pigments that could absorb blue light (which is plentiful in its environment) then the plant would thrive. It could pass on its genes and its offspring would have a higher fitness than plants that could only absorb red light. The remaining plants would only use the blue colors of the visible light spectrum because it wouldn't be effient to have ~~photo~~ pigments that could absorb red lights.

ANSWER PAGE FOR QUESTION 2

a) The absorbtion speetrum in Graph II is from the pigment chlorophyll a. The absorbtion speetrum shows strong refleetion of wavelengths from about 480 nm to 590 nm, which is perceived by humans as green. (The cyan and yellow components also mix to form green). The speetrum in Graph I is from the pigment bacteriorhodopsin. The speetrum shows strong refleetion of violet and reed wavelengths, which is why bacteriorhodopsin appears purple.

b) The organisms under the 430 nm light will have the highest rate of photosynthesis, beeause the chlorophyll a in those organisms have a high rate of absorbtion for 430 nm. Because a lot of light energy is absorbed, the organisms can use that energy for photosynthesis. The organisms under the 650 nm wavelength light will have medium levels of photosynthetic activity. The chlorophyll a in these organisms

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have deeent absorbtion for 650 nm, so a medium amount of energy is available for photosynthesis. The organisms under the 550 nm light will have the lowest rate of photosynthesis. Because chlorophyll a absorbs almost no light at 550 nm, very little energy is availible for photosynthesis.

c)

ANSWER PAGE FOR QUESTION 2

a. The bacteriorhodopsin pigment was used to generate Graph I because on the interval (350 nm, 600 nm) it has a relative minimum for absorption near 450 nm which is included in the wavelength range for violet. This means that at this wavelength the light was not absorbed but reflected, giving the appearance of the color at that wavelength. This pigment is found in purple photosynthetic bacteria. The chlorophyll a was used to generate Graph II, as chlorophyll is found in green plants, meaning that green is reflected and not absorbed. In this graph, relative absorbance is near 0 at 550 nm, which is included in the wavelength range for green (495 nm - 570 nm).

b. The 3rd group will have the fastest rate of photosynthesis, as the graph shows a peak of absorbance at approximately 430 nm. This is at the violet end of the light spectrum and is the furthest in the graph from the green wavelength. The second fastest rate of photosynthesis would occur in the first group, as is represented on the graph and in the fact that this wavelength is on the red end of the spectrum and the second furthest from green in the graph. The second group would have a very slow rate of photosynthesis. The graph shows an absorbance of nearly zero as this wavelength is in the green area of the spectrum, which is not absorbed by

2C2

ADDITIONAL PAGE FOR ANSWERING QUESTION 2

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Question 2

Question 2 was written to the following Learning Objectives in the AP Biology Curriculum Framework: 1.2, 1.12, 1.13, 1.25, 2.5, 2.24, 4.4, 4.5, and 4.6.

Overview

Question 2 asks students to work with scientific theory and evidence to explain how the processes of natural selection and evolution could have resulted in different photosynthetic organisms absorbing light within different ranges of the visible light spectrum. Students were asked to use experimental data (absorption spectra) to identify two different photosynthetic pigments and to explain how the data support their identification. Students were then presented with a description of an experiment for investigating how the wavelength of available light affects the rate of photosynthesis in autotrophic organisms. Students were asked to predict the relative rates of photosynthesis in three treatment groups, each exposed to a different wavelength of light, and to justify their prediction using their knowledge and understanding about the transfer of energy in photosynthesis. Finally, students were asked to propose a possible evolutionary history of plants by connecting differences in resource availability with different selective pressures that drive the process of evolution through natural selection.

Sample: 2A
Score: 10

The response earned 1 point in part (a) for identifying bacteriorhodopsin is the pigment used to generate the absorption spectrum in graph I and chlorophyll *a* is the pigment used for graph II.

The response earned 1 point in part (a) for explaining that bacteriorhodopsin is purple because it reflects rather than absorbs purple light. The response earned 1 point for explaining that chlorophyll *a* is green because green light is reflected by the pigment.

The response earned 1 point in part (b) for predicting that the second group (550 nm) will have the lowest level of photosynthesis. The response earned 1 point for justifying the prediction by stating that the rate of photosynthesis is proportional to the low amount of light absorbed and thus will not be able to excite electrons to drive photosynthesis.

The response earned 1 point in part (b) for predicting that the first group (650 nm) will have an intermediate rate of photosynthesis. The response earned 1 point for justifying the prediction by stating that the rate of photosynthesis is proportional to the moderate amount of light absorbed and thus the moderate amount of energy available to drive photosynthesis.

The response earned 1 point in part (b) for communicating a completed argument by stating that the remaining group (group 3) will have the highest rate of photosynthesis because it has the highest absorption and thus the highest amount of energy available to drive photosynthesis.

The response earned 1 point in part (c) for proposing that an ancestral plant in an aquatic environment would have access to mostly blue and cyan colors of light. The response earned 1 point for providing reasoning that a plant that could use the available light would be selected for (i.e., have the highest fitness) in that environment.

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Question 2 (continued)

Sample: 2B
Score: 8

The response in earned 1 point in part (a) for identifying bacteriorhodopsin is the pigment used to generate the absorption spectrum in graph I and chlorophyll *a* is the pigment used for graph II.

The response earned 1 point in part (a) for explaining that the pigment in Graph II appears green because it reflects light in the green wavelengths. The response earned 1 point for explaining that the pigment in Graph I appears purple because it reflects light in the violet and red wavelengths.

The response earned 1 point in part (b) for predicting that group 3 (430 nm) will have the highest rate of photosynthesis. The response earned 1 point for justifying the prediction by stating that the rate of photosynthesis is proportional to the high amount of light energy absorbed.

The response earned 1 point in part (b) for predicting that group 1 (650 nm) will have intermediate levels of photosynthetic activity. The response earned 1 point for justifying the prediction by stating that the rate of photosynthesis is proportional to the medium amount of light energy absorbed.

The response earned 1 point in part (b) for communicating a completed argument that the remaining group (550 nm) will have the lowest rate of photosynthesis because very little light energy is absorbed.

Sample: 2C
Score: 6

The response in earned 1 point in part (a) for identifying bacteriorhodopsin is the pigment used to generate the absorption spectrum in graph I and chlorophyll *a* is the pigment used for Graph II.

The response earned 1 point in part (a) for explaining that the pigment in Graph I appears purple because it reflects light in the violet wavelengths. The response earned 1 point for explaining that the pigment in Graph II appears green because it reflects light in the green wavelengths.

The response earned 1 point in part (b) for predicting that the third group (430 nm) will have the highest rate of photosynthesis. The response earned 1 point for predicting that the first group (650 nm) will have an intermediate rate of photosynthesis.

The response earned 1 point in part (b) for communicating a completed argument that the remaining group (550 nm) will have the lowest rate of photosynthesis.