AP® BIOLOGY
2016 SCORING GUIDELINES

Question 2

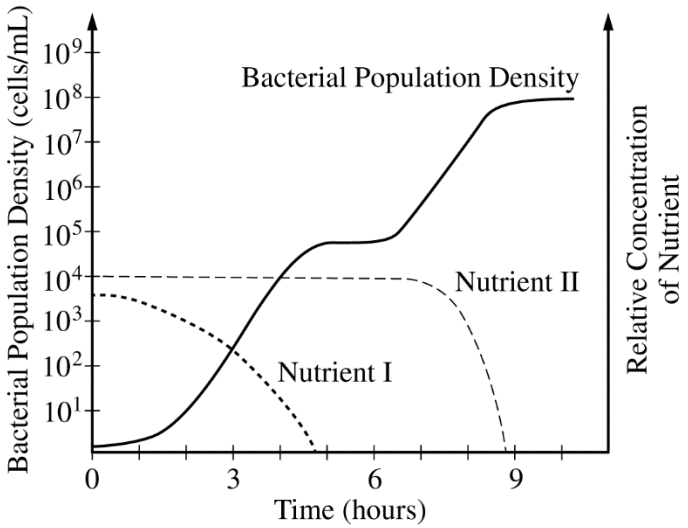

Figure 1. Bacterial population growth in the presence of two nutrients (nutrient I and nutrient II)

Bacteria can be cultured in media with carefully controlled nutrient composition. The graph above shows the growth of a bacterial population in a medium with limiting amounts of two nutrients, I and II.

(a) **Estimate** the maximum population density in $\frac{\text{cells}}{\text{mL}}$ for the culture. Using the data, **describe** what prevents further growth of the bacterial population in the culture. **(2 points)**

Estimate (1 point)

- 10^8

Description (1 point)

- When both nutrients are depleted

(b) Using the data, **calculate** the growth rate in $\frac{\text{cells}}{\text{mL}\times\text{hour}}$ of the bacterial population between hours 2 and 4. **(1 point)**.

Calculation (1 point)

- 4,995

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Question 2 (continued)

(c) **Identify** the preferred nutrient source of the bacteria in the culture over the course of the experiment. Use the graph to **justify** your response. **Propose** ONE advantage of the nutrient preference for an individual bacterium. **(3 points)**

Identification (1 point)

- Nutrient I is the preferred nutrient.

Justification (1 point)

- When both nutrients are present in the growth medium, only nutrient I is used.
- Nutrient II is only used after nutrient I is depleted.

Proposed advantage (1 point)

- Do not spend energy making enzymes/proteins that the cell doesn't need.
- Do not have to express all metabolic genes at once.
- The preferred nutrient provides more energy.

(d) **Describe** how nutrient I most likely regulates the genes for metabolism of nutrient I and the genes for metabolism of nutrient II. **Provide** TWO reasons that the population does not grow between hours 5 and 6. **(4 points)**

Description (2 points)

- Nutrient I promotes expression of genes required for metabolism of nutrient I.
- Nutrient I represses expression of genes required for metabolism of nutrient II.

Reasoning (2 points)

- Nutrient I is depleted from the growth medium OR neither nutrient is being consumed.
- Takes time to produce proteins/enzymes required to metabolize nutrient II.

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The maximum bacterial population density is 10^8 cells/mL in this culture. Further growth beyond this point is prevented by limited resources; both nutrient 1 and nutrient 2 are entirely depleted.

The growth rate between hours 2 and 4 is

$$\frac{10^4 \text{ cells/mL} - 10^1 \text{ cells/mL}}{2 \text{ hrs}} = \frac{4995 \text{ cells}}{\text{mL} \times \text{hr}}$$

The bacteria prefer nutrient 1, as evidenced by the fact that they consume nutrient I first, as shown by nutrient 1's depletion prior to nutrient II's depletion. The amount of nutrient II only begins to decline, & be consumed, once nutrient I is already gone. Nutrient I probably is a more efficient source of energy, or, in other words, requires the bacteria to expend less energy relative to the energy gained from the nutrient. This preference would be an advantage to an individual bacterium because it could then expend more energy on reproduction.

When nutrient 1 is present in the environment, it turns on the genes that allow the bacteria to digest nutrient 1. It probably does this by activating a phosphorylation cascade that produces a molecule that binds to the promoter and allow RNA polymerase to bind. This allows the genes to be transcribed, leading to

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the uptake and consumption of nutrient I. At the same time, nutrient I probably also prevents the genes for digesting nutrient II from being transcribed, giving the bacteria a preference for nutrient I. It probably does this through a phosphorylation cascade that produces an inhibitor that prevents RNA polymerase from binding to the genes for nutrient II. Only when nutrient I is absent will nutrient II be absorbed.

The population does not grow between hours 5 and 6 because it is not consuming nutrients. It could not be consuming nutrient II because it takes time for the inhibitor caused by nutrient I to be released so that the genes for ~~digesting~~ consuming nutrient II can be transcribed. Alternately, the inhibitor could be released quickly, but the proteins to uptake nutrient II could take a long time to produce, and thus the population does not consume nutrients for that hour. Perhaps the bacteria have a mechanism for waiting after the depletion of nutrient I to see if more nutrient will become available before diving to nutrient II.

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a) The maximum population density for the bacteria is approximately 10^8 cells/mL. The population does not exceed this density, or its carrying capacity, due to environmental restrictions. In this example, the limiting factor for maximum density is the nutrients available in the growth medium.

b) Between the 2nd and 4th hour, the population grew by 9,990 cells/mL. The growth rate then is 4,995 cells/mL Hr.

c) The preferred nutrient of the bacteria is Nutrient I. The graph shows that Nutrient I is preferred because it is depleted before Nutrient II is even started to be utilized. An advantage of Nutrient preference for an individual is that ONLY 1 enzyme needs to be synthesized, saving the ~~extra~~ extra energy needed to produce multiple enzymes.

d) Nutrient I most likely acts as an inducer molecule for the enzyme gene to break down nutrient I and a repressor for the gene for the enzyme that

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breaks down nutrient II. When Nutrient I is present in the environment, the bacteria prefers using it, so starts transcription and translation of an enzyme that breaks down Nutrient I and inhibits translation OF Nutrient II enzyme. The Nutrient I molecules do this by attaching to a repressor protein that either is removed from the operon to allow transcription or attached to the operon to prevent transcription. Between hours 5-6, the bacteria need some time to switch from making Nutrient I enzyme to Nutrient II enzyme. One possible reason is that the Nutrient II enzyme gene is actually found in plasmid DNA. The plasmid then needs time to be conjugated with the other bacteria via sex pili. Another possible reason is that residual Nutrient I is still bound to the repressor protein and needs some time to detach.

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A) The carrying capacity is around 10^8 cells/mL because the lack of nutrients prevents the population from growing further.

B) $\frac{10^4 - 10^1}{4-2} = \frac{9990}{2} = 4995$ cells/mL/hour

C) The preferred nutrient source of the population was nutrient I because this was the nutrient that was consumed first. An individual bacterium may have a more efficient method of utilizing the energy from a specific nutrient, which would be an advantage in an environment rich in that nutrient.

D) Nutrient I may regulate the metabolism because the population grows quickly with this nutrient and stops without it. It may also play a role in the operon that activates the genes needed for nutrient II. The population does not grow between hours 5 and 6 because the population is stabilizing and adjusting to a new food source and because there is no more nutrient I, which was responsible for driving their energy production and growth.

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Question 2

Question 2 was written to the following Learning Objectives in the AP® Biology Curriculum Framework: 2.1, 2.24, 2.37, 2.8, 3.21, 3.40, 4.11, 4.14, 4.15, and 4.23.

Overview

This question was based on a graph showing the growth of a bacterial population in the presence of limiting amounts of two different nutrients, nutrient I and nutrient II. Students were also presented data showing the relative concentrations of the two nutrients in the growth medium during the experiment. Students were asked to use the data to estimate the maximum population density in the culture and to describe what likely prevents further growth of the population. Students were then asked to calculate the rate of growth of the bacterial population for a specific time period. Students were asked to identify the preferred nutrient source of the bacteria, to justify their selection using the data, and to propose an advantage of displaying a preference for one nutrient over another. Finally, students were asked to propose a mechanism whereby nutrient I may regulate the expression of genes involved in the metabolism of both nutrient I and nutrient II, and to provide two reasons for the lag in population growth that occurs midway through the experiment.

Sample: 2A
Score: 10

The response earned 1 point in part (a) for estimating that the maximum population density (cells/mL) for the culture is 10^8. The response earned 1 point in part (a) for describing that both nutrient I and nutrient II are depleted. The response earned 1 point in part (b) for calculating a growth rate (cells/mL/hour) of 4,995. The response earned 1 point in part (c) for identifying that the bacteria prefer nutrient I. The response earned 1 point in part (c) for the justification that the amount of nutrient II only begins to decline once nutrient I is already gone. The response earned 1 point in part (c) for proposing that an advantage of nutrient preference is that the bacteria expend less energy relative to the energy gained from the nutrient. The response earned 1 point in part (d) for describing that when nutrient I is present in the environment, it turns on the genes that allow the bacteria to digest nutrient I. The response earned 1 point in part (d) for describing that nutrient I prevents the genes for digesting nutrient II from being transcribed. The response earned 1 point in part (d) for reasoning that the population did not grow between hours 5 and 6 because it is not consuming nutrients. The response earned 1 point in part (d) for reasoning that the population did not grow between hours 5 and 6 because the proteins that uptake nutrient II could take a long time to produce.

Sample: 2B
Score: 8

The response earned 1 point in part (a) for estimating that the maximum population density (cells/mL) for the culture is 10^8. The response earned 1 point in part (b) for calculating a growth rate in cells/mL/hour of 4,995. The response earned 1 point in part (c) for identifying that the preferred nutrient of the bacteria is nutrient I. The response earned 1 point in part (c) for the justification that nutrient I is depleted before nutrient II begins to be utilized. The response earned 1 point in part (c) for proposing that an advantage of nutrient preference is that the cells save energy by producing only the enzymes they need. The response earned 1 point in part (d) for describing that nutrient I induces expression of the genes that allow the bacteria to digest nutrient I. The response earned 1 point in part (d) for describing that nutrient I most likely represses expression of the genes that allow the bacteria to digest nutrient II. The response earned 1 point in part (d) for reasoning that the population did not grow because the bacteria need time to produce the enzymes to metabolize nutrient II.

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Question 2 (continued)

Sample: 2C
Score: 6

The response earned 1 point in part (a) for estimating that the maximum population density (cells/mL) for the culture is 10^8. The response earned 1 point in part (a) for describing that the lack of nutrients prevents further growth. The response earned 1 point in part (b) for calculating a growth rate in cells/mL/hour of 4,995. The response earned 1 point in part (c) for identifying that nutrient I is the preferred nutrient. The response earned 1 point in part (c) for proposing that an advantage of nutrient preference is that it is a more efficient method of utilizing energy from a specific nutrient. The response earned 1 point in part (d) for reasoning that the population did not grow because there is no more nutrient I.