

Question 2: Interpreting and Evaluating Experimental Results with Graphing

9 points

To investigate how increases in environmental temperatures affect the metabolism of certain organisms, researchers incubated liver cells from toads at different temperatures and measured two markers of metabolic activity (Table 1): the rate of oxygen consumption and the rate of ATP synthesis.

TABLE 1. RATE OF OXYGEN CONSUMPTION AND ATP SYNTHESIS AT DIFFERENT TEMPERATURES

Metabolic Marker	20°C	25°C	30°C
Rate of Oxygen Consumption (nmol/min/mg of mitochondrial protein $\pm 2SE_{\bar{X}}$)	12.8 ± 2.2	16.5 ± 2.0	22.1 ± 0.7
Rate of ATP Synthesis (nmol/min/mg of mitochondrial protein $\pm 2SE_{\bar{X}}$)	12.6 ± 1.6	16.8 ± 2.0	21.07 ± 0.8

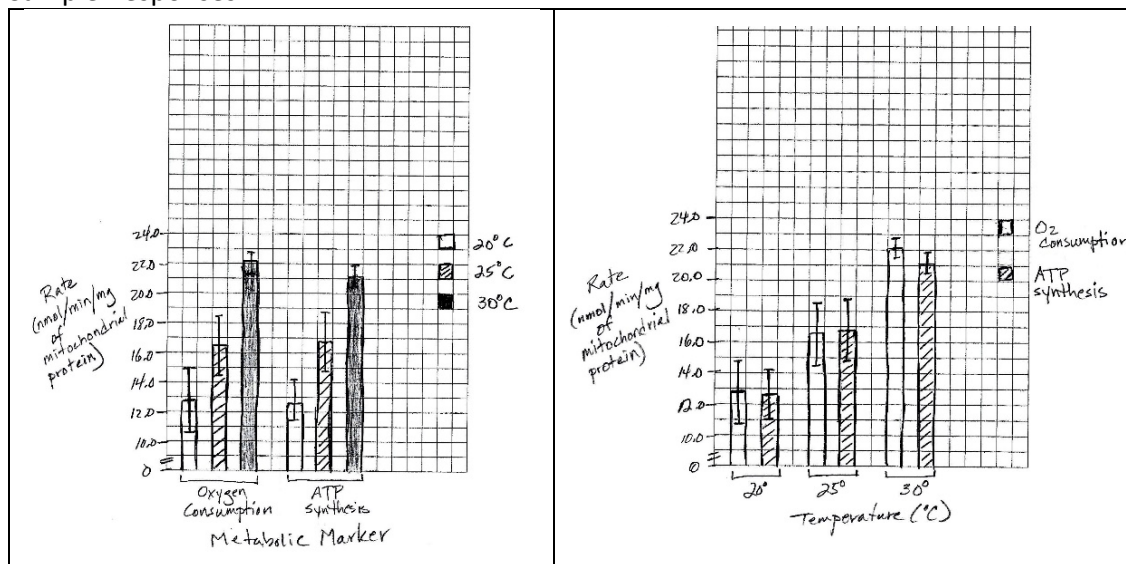
(a) Describe the role of water in the hydrolysis of ATP. 1 point

Accept one of the following:

- Water is added in the process of cleaving/splitting (a phosphate from) ATP.
- Water breaks down/splits ATP.

(b) Using the template in the space provided for your response, **construct** a bar graph that represents the data shown in Table 1. Your graph should be appropriately plotted and labeled. 1 point

Sample Responses:



- Data are represented in a bar graph.

Using the template in the space provided for your response, **construct** a bar graph that represents the data shown in Table 1. Your graph should be appropriately plotted and labeled. 1 point

Using the template in the space provided for your response, **construct** a bar graph that represents the data shown in Table 1. Your graph should be appropriately plotted and labeled. **1 point**

- Data points and error bars are correctly plotted.

Based on the data provided, **determine** the temperature in °C at which the rate of oxygen consumption is different from the rate of oxygen consumption at 25°C. **1 point**

- 30

Total for part (b) 4 points

(c) Based on the data in Table 1, **describe** the effect of temperature on the rate of ATP synthesis in liver cells from toads. **1 point**

Accept one of the following:

- As the temperature increases, the rate of ATP synthesis also increases.
- There is a positive relationship (between temperature and ATP synthesis).
- Temperature and ATP synthesis are directly correlated.

Based on the data in Table 1, **calculate** the average amount of oxygen consumed, in nmol, for 10 mg of mitochondrial protein after 10 minutes at 25°C. **1 point**

1,650 [16.5 nmol/min/mg × 10 mg × 10 min]

Total for part (c) 2 points

(d) Oligomycin is a compound that can block the channel protein function of ATP synthase. **Predict** the effects of using oligomycin on the proton gradient across the inner mitochondrial membrane. **1 point**

Accept one of the following:

- (The proton gradient) will increase/become steeper (and may eventually plateau).
- The difference in the concentration of protons/pH (across the inner mitochondrial membrane) will increase.
- There will be an increase in the concentration of protons/a decrease in pH in the intermembrane space relative to that found within the mitochondrial matrix.

Justify your prediction. **1 point**

Accept one of the following:

- (Without protons being able to flow back into the matrix through ATP synthase), more protons will accumulate in the intermembrane space/between the two mitochondrial membranes.
- (Without protons being able to flow back into the matrix through ATP synthase), there will be a lower pH in the intermembrane space/between the two mitochondrial membranes.
- Protons will not be able to flow across the membrane (through ATP synthase), but the electron transport chain will still pump protons into the intermembrane space.

Total for part (d) 2 points

Total for question 2 9 points

Question 2: Interpreting and Evaluating Experimental Results with Graphing

9 points

Elevated levels of CO_2 increase the rate of photosynthesis and growth in plants. Scientists studying the mechanisms involved in these increases examined a variety of species and found that when plants are exposed to elevated levels of CO_2 , there is an increase in the number of chloroplasts per cell. To investigate whether the elevated levels of CO_2 have a similar effect on the number of mitochondria in plant cells, the scientists then selected six of these species to quantify the number of mitochondria per cell when the plants were exposed to both normal and elevated levels of CO_2 (Table 1).

TABLE 1. AVERAGE NUMBER OF MITOCHONDRIA IN PLANTS EXPOSED TO NORMAL AND ELEVATED LEVELS OF CO_2

Species	Mitochondria at Normal CO_2 (per 100 μm^2 of cell area) $\pm 2\text{SE}_{\bar{x}}$	Mitochondria at Elevated CO_2 (per 100 μm^2 of cell area) $\pm 2\text{SE}_{\bar{x}}$
1	1.0 ± 0.10	1.6 ± 0.10
2	0.4 ± 0.05	0.9 ± 0.08
3	0.5 ± 0.07	0.9 ± 0.10
4	0.3 ± 0.03	0.6 ± 0.06
5	0.7 ± 0.06	1.5 ± 0.22
6	1.3 ± 0.15	2.4 ± 0.22

(a) **Describe** the role of the inner mitochondrial membrane in cellular respiration.

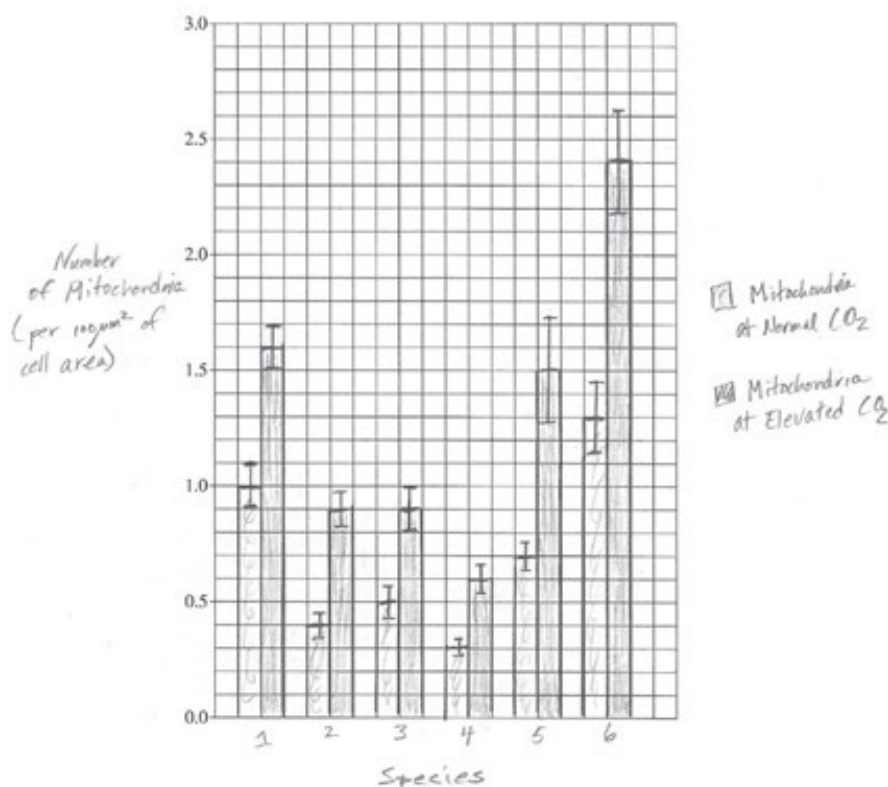
1 point

Accept one of the following:

- It provides the location for the components of the electron transport chain/ATP synthase/oxidative phosphorylation.
- It separates (reactions in) the intermembrane space from (reactions in) the matrix.
- It allows the establishment of a proton gradient.

- (b) Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1. **1 point**

Sample response:



- Appropriate labelling

Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1. **1 point**

- Data are represented in a bar/modified bar graph.

Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1. **1 point**

- Data points and error bars are correctly plotted.

Determine which species show(s) a difference in the number of mitochondria between normal and elevated levels of CO₂. **1 point**

- All of the species

Total for part (b) 4 points

- (c) Based on the data in Table 1, **describe** the relationship between the level of CO₂ and the average number of mitochondria per unit area of a cell. **1 point**

Accept one of the following:

- The number of mitochondria is greater under conditions of elevated CO₂ (than under normal CO₂).
- It is a positive relationship/correlation.

(d) The leaves of a particular plant species are typically green, but scientists notice a plant in which the leaves have white stripes. They determine that the stripes result from a mutation in mitochondrial DNA that interferes with the development of chloroplasts. The scientists crossed plants using pollen from the plant with white-striped leaves and ovules from a plant with green leaves. Predict the phenotype(s) of the leaves of offspring produced from this cross.	1 point
The leaves will <u>be (all) green/not have white stripes</u>.	
Provide reasoning to justify your prediction.	1 point
(All offspring will have the same leaf phenotype as the ovule-producing plant because) mitochondria are <u>maternally inherited/transferred by the ovule</u>.	
Explain why plants with the same genotype are able to differ in the structure and/or number of certain organelles in response to changes in atmospheric levels of CO ₂ .	1 point
(Plants have different phenotypes because) changes in <u>CO₂ levels/the environment</u> affect the expression of certain genes.	
Total for part (d)	3 points
Total for question 2	9 points

Question 3: Scientific Investigation**4 points**

Researchers hypothesize that the plant compound resveratrol improves mitochondrial function. To test this hypothesis, researchers dissolve resveratrol in dimethyl sulfoxide (DMSO). The solution readily passes through cell membranes. They add the resveratrol solution to mammalian muscle cells growing in a nutrient-rich solution (culture medium) that contains glucose. They measure ATP production at several time points after the addition of the resveratrol solution and find an increase in ATP production by the muscle cells.

(a)	Describe the primary advantage for a mammalian muscle cell in using aerobic respiration over fermentation. • More ATP (per glucose molecule) is produced by aerobic respiration.	1 point
(b)	Identify an appropriate negative control for this experiment that would allow the researchers to conclude that ATP is produced in response to the resveratrol treatment. Accept one of the following: • The researchers must run the experiment without adding resveratrol. • The researchers must treat the cells with DMSO alone.	1 point
(c)	Predict the effect on short-term ATP production when resveratrol-treated mammalian muscle cells are grown in a culture medium that lacks glucose or other sugars. Accept one of the following: • No ATP production • Reduced ATP production	1 point
(d)	The researchers find that resveratrol stimulates the production of components of the electron transport chain. The researchers claim that treatment with resveratrol will also increase oxygen consumption by the cells if glucose is not limiting. Justify the claim. • More electrons can be transferred so that more oxygen is required as the final electron acceptor.	1 point
Total for question 3		4 points

2019

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Question 1

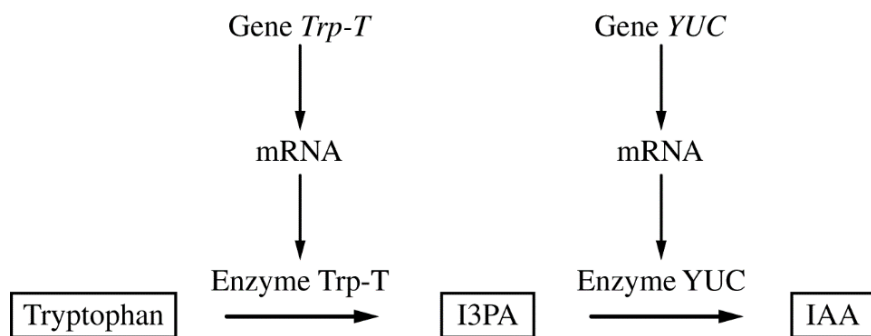


Figure 1. Model of two-step enzymatic plant pathway for synthesis of IAA from tryptophan

Auxins are plant hormones that coordinate several aspects of root growth and development. Indole-3-acetic acid (IAA) is an auxin that is usually synthesized from the amino acid tryptophan (Figure 1). Gene *Trp-T* encodes an enzyme that converts tryptophan to indole-3-pyruvic acid (I3PA), which is then converted to IAA by an enzyme encoded by the gene *YUC*.

- (a) **Circle** ONE arrow that represents transcription on the template pathway. **Identify** the molecule that would be absent if enzyme YUC is nonfunctional.

Circle (1 point)

- Circle around either arrow pointing from a gene (*Trp-T* or *YUC*) to mRNA

Identification (1 point)

- IAA

- (b) **Predict** how the deletion of one base pair in the fourth codon of the coding region of gene *Trp-T* would most likely affect the production of IAA. **Justify** your prediction.

Prediction (1 point)

- Reduction in IAA production OR No production of IAA

Justification (1 point)

- The mutation will result in the translation of an inactive/nonfunctional Trp-T enzyme.
- The mutation will result in no translation of the Trp-T enzyme.
- The mutation will result in no/reduced production of I3PA.

- (c) **Explain** one feedback mechanism by which a cell could prevent production of too much IAA without limiting I3PA production.

Explanation (2 points)

- Negative feedback/feedback inhibition/increasing amounts of IAA inhibits the pathway.
- Production of YUC enzyme is inhibited OR YUC enzyme activity is inhibited.

2019 SCORING GUIDELINES**Question 1 (continued)**

- (d) Rhizobacteria are a group of bacteria that live in nodules on plant roots. Rhizobacteria can produce IAA and convert atmospheric nitrogen into forms that can be used by plants. Plants release carbon-containing molecules into the nodules. Based on this information, **identify** the most likely ecological relationship between plants and rhizobacteria. **Describe** ONE advantage to the bacteria of producing IAA.

Identification (1 point)

- Mutualism

Description (1 point)

- Increases habitat/number of nodules for the rhizobacteria.
- The bacteria receive carbon/carbon-containing molecules (as a result of increased plant growth).

- (e) A researcher removed a plant nodule and identified several “cheater” rhizobacteria that do not produce IAA or fix nitrogen. **Describe** the evolutionary advantage of being a bacterial cheater in a population composed predominantly of noncheater bacteria. Plants can adjust the amount of carbon-containing molecules released into nodules in response to the amount of nitrogen fixed in the nodule. **Predict** the change in the bacterial population that would cause the plant to reduce the amount of carbon-containing molecules provided to the nodule.

Description (1 point)

- Cheaters/bacteria that benefit without producing IAA/fixing nitrogen have more energy for reproduction.

Prediction (1 point)

- Decrease in the nitrogen-fixing/noncheater bacteria
- Decrease in the amount of nitrogen fixed (by bacteria)

2019 SCORING GUIDELINES**Question 2**

A student studying two different aquatic, plant-eating, unicellular protist species (species A and B) designed an experiment to investigate the ecological relationship between the two species (Table 1).

TABLE 1. EXPERIMENTAL TREATMENT GROUPS

Group I.	Species A and B are each grown in separate containers.
Group II.	Species A and B are grown together in the same container.

In treatment group I, the student placed 10 individuals of species A into a container with liquid growth medium and 10 individuals of species B into a separate container with an equal amount of the same liquid growth medium. In treatment group II, the student placed 5 individuals of each species into a single container with the liquid growth medium. The student then maintained the containers under the same environmental conditions and recorded the number of individuals in each population at various time points. The results are shown in Table 2.

TABLE 2. NUMBER OF INDIVIDUALS IN EACH PROTIST POPULATION IN BOTH TREATMENT GROUPS

Time (h)	Group I. Grown Separately		Group II. Grown Together	
	Species A	Species B	Species A	Species B
0	10	10	5	5
10	100	50	45	20
20	400	200	100	50
30	1100	500	250	25
40	1400	650	525	20
50	1500	700	900	10
60	1500	700	1250	0
70	1500	700	1400	0

(a) The growth curves for species B in group I and for species A in group II (shaded columns) have been plotted on the template. Use the template to **complete** an appropriately labeled line graph to illustrate the growth of species A in treatment group I and species B in treatment group II (unshaded columns).

Completion (3 points)

- Correctly plotted lines for remaining two treatments
- Correctly labeled axes including units
- Correctly labeled data lines

2019 SCORING GUIDELINES**Question 2 (continued)**

(b) As shown in the table, the researcher established treatment group II with 5 individuals of each species. **Provide reasoning** for the reduced initial population sizes.

Reasoning (1 point)

- Reduced initial population sizes keep the total number of organisms the same in all containers.
- Reduced initial population sizes serve as a control for population density.

(c) The student claims that species A and B compete for the same food source. **Provide TWO pieces of evidence** from the data that support the student's claim.

Evidence (1 point per row; 2 points max.)

Comparison of Groups	Evidence
I-A to II-A	• Growth rate is faster in I/slower in II
I-A to II-A	• Grows to a higher population density in I/lower population density in II
I-B to II-B	• Growth rate is faster in I/slower in II
I-B to II-B	• Grows to a higher population density in I/lower population density in II/ II dies out/II goes to zero

(d) **Predict** TWO factors that most likely limit the population growth of species A in treatment group I.

Prediction (2 points)

Acceptable factors include:

- Food
- Space
- Metabolic waste
- Dissolved oxygen

(e) Many protists contain an organelle called a contractile vacuole that pumps water out of the cell. The student repeated the experiment using a growth medium with a lower solute concentration. **Predict** how the activity of the contractile vacuole will change under the new experimental conditions. **Justify** your prediction.

Prediction (1 point)

- The contractile vacuole will be more active.

Justification (1 point)

- The environment is hypotonic with respect to the cell.
- The cell is hypertonic with respect to environment.
- Water has entered the cell (which could cause lysis).
- The cell has lower water potential than the environment/the environment has higher water potential than the cell.

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Question 3

The pyruvate dehydrogenase complex (PDC) catalyzes the conversion of pyruvate to acetyl-CoA, a substrate for the Krebs (citric acid) cycle. The rate of pyruvate conversion is greatly reduced in individuals with PDC deficiency, a rare disorder.

(a) **Identify** the cellular location where PDC is most active.

Identification (1 point)

- Mitochondria
- Mitochondrial matrix

(b) **Make a claim** about how PDC deficiency affects the amount of NADH produced by glycolysis AND the amount of NADH produced by the Krebs (citric acid) cycle in a cell. **Provide reasoning** to support your claims based on the position of the PDC-catalyzed reaction in the sequence of the cellular respiration pathway.

(1 point per row; 2 points max.)

	Claim	Reasoning
Glycolysis	No change	• Glycolysis continues; PDC is not needed. • Glycolysis occurs before conversion of pyruvate to acetyl-CoA.
Krebs cycle	Decrease	• The Krebs cycle is greatly reduced/slowed down if there is no/less acetyl-CoA. • The Krebs cycle occurs after conversion of pyruvate to acetyl-CoA.

(c) PDC deficiency is caused by mutations in the *PDHA1* gene, which is located on the X chromosome. A male with PDC deficiency and a homozygous female with no family history of PDC deficiency have a male offspring. **Calculate** the probability that the male offspring will have PDC deficiency.

Calculation (1 point)

- The probability of inheritance is 0.
- The offspring cannot/will not have PDC deficiency.

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Question 4

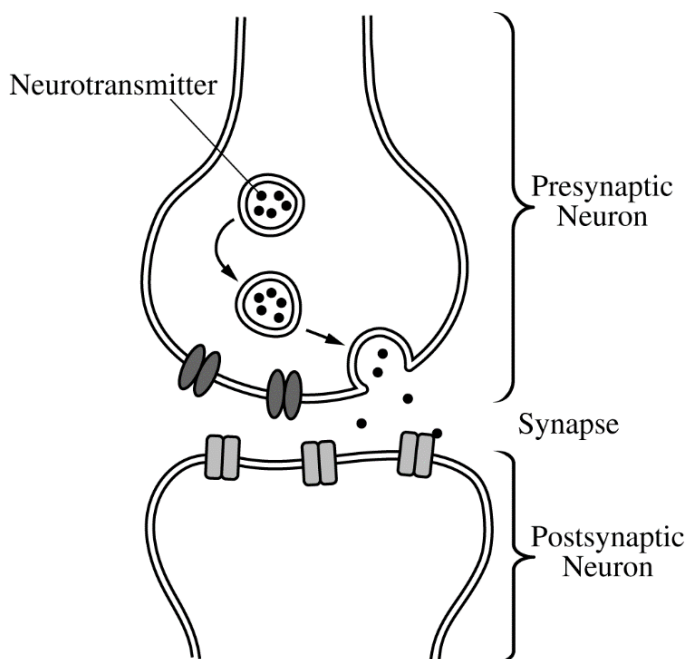


Figure 1. Release of neurotransmitters into the synapse in response to an action potential

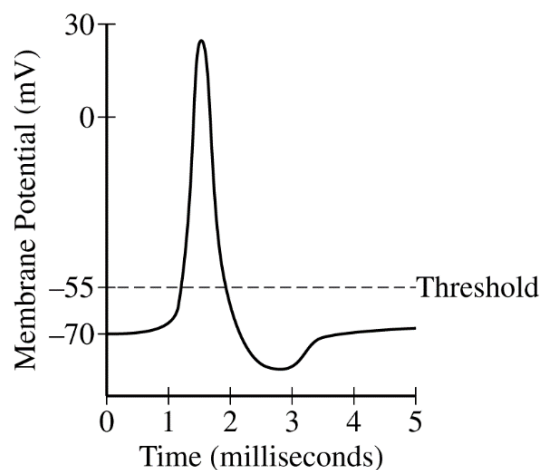


Figure 2. Model of a typical action potential in a neuron

Acetylcholine is a neurotransmitter that can activate an action potential in a postsynaptic neuron (Figures 1 and 2). A researcher is investigating the effect of a particular neurotoxin that causes the amount of acetylcholine released from presynaptic neurons to increase.

(a) **Describe** the immediate effect of the neurotoxin on the number of action potentials in a postsynaptic neuron. **Predict** whether the maximum membrane potential of the postsynaptic neuron will increase, decrease, or stay the same.

Description (1 point)

- It will increase the number of action potentials.

Prediction (1 point)

- It will stay the same.

(b) The researcher proposes two models, A and B, for using acetylcholinesterase (AChE), an enzyme that degrades acetylcholine, to prevent the effect of the neurotoxin. In model A, AChE is added to the synapse. In model B, AChE is added to the cytoplasm of the postsynaptic cell. **Predict** the effectiveness of EACH proposed model. **Provide reasoning** to support your predictions.

(1 point per row; 2 points max.)

	Prediction	Reasoning
Model A	Effective	Acetylcholine is in the synapse.
Model B	Not effective	Acetylcholine is not in the cytoplasm of the postsynaptic cell.

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Question 5

TABLE 1. DIVERGENCE (IN PERCENT) OF MITOCHONDRIAL DNA SEQUENCES AMONG FIVE PRIMATE SPECIES

	Human	Gorilla	Orangutan	Gibbon	Chimpanzee
Human	-	10.3	16.1	18.1	8.8
Gorilla		-	16.7	18.9	10.6
Orangutan			-	18.9	17.2
Gibbon				-	18.9
Chimpanzee					-

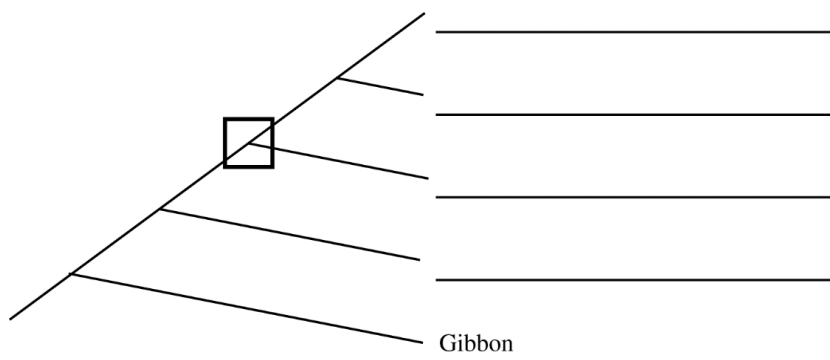
A researcher studying the evolutionary relationship among five primate species obtained data from a sequence of mitochondrial DNA (mtDNA) from a representative individual of each species. The researcher then calculated the percent divergence in the sequences between each pair of primate species (Table 1).

(a) Based on fossil data, the researcher estimates that humans and their most closely related species in the data set diverged approximately seven million years ago. Using these data, **calculate** the rate of mtDNA percent divergence per million years between humans and their most closely related species in the data set. Round your answer to two decimal places.

Calculation (1 point)

- 1.25 OR 1.26

(b) Using the data in the table, **construct** a cladogram on the template provided. **Provide reasoning** for the placement of gibbons as the outgroup on the cladogram.

**Construction (1 point)**

- From top to bottom: Human/Chimpanzee (interchangeable), Gorilla, Orangutan

Reasoning (1 point)

- Gibbon mtDNA is the least similar (to all of the other species)/most different (from all of the other species).
- Gibbon mtDNA is the most divergent (from all of the other species).

2019 SCORING GUIDELINES**Question 5 (continued)**

(c) On the cladogram, **draw** a circle around all of the species that are descended from the species indicated by the node within the square.

Circle (1 point)

- Circle species 1, 2, and 3, as numbered from the top.

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Question 6

	MEDIUM	STRAINS		
		Wild Type	Mutant 1	Mutant 2
Treatment I	All amino acids present	+	+	+
Treatment II	No amino acids present	+	–	–
Treatment III	All amino acids present EXCEPT methionine	+	–	+
Treatment IV	All amino acids present EXCEPT leucine	+	+	–

Table 1. The data show the growth of haploid *Saccharomyces cerevisiae* yeast strains on media that differ in amino acid content. A plus sign (+) indicates that the yeast strains grow, and a minus sign (–) indicates that the strains do not grow.

The yeast *Saccharomyces cerevisiae* is a single-celled organism. Amino acid synthesis in yeast cells occurs through metabolic pathways, and enzymes in the synthesis pathways are encoded by different genes. The synthesis of a particular amino acid can be prevented by mutation of a gene encoding an enzyme in the required pathway.

A researcher conducted an experiment to determine the ability of yeast to grow on media that differ in amino acid content. Yeast can grow as both haploid and diploid cells. The researcher tested two different haploid yeast strains (Mutant 1 and Mutant 2), each of which has a single recessive mutation, and a haploid wild-type strain. The resulting data are shown in Table 1.

(a) **Identify** the role of treatment I in the experiment.

Identification (1 point)

- (Positive) control (for yeast growth).
- To test the viability of all yeast strains.
- Treatment I allows the researcher to be confident that changes in experimental outcome are due to differences in treatments.

(b) **Provide reasoning** to explain how Mutant 1 can grow on treatment I medium but cannot grow on treatment III medium.

Reasoning (1 point)

- Mutant 1 can use methionine when it is present in the medium, but Mutant 1 cannot synthesize methionine.

(c) Yeast mate by fusing two haploid cells to make a diploid cell. In a second experiment, the researcher mates the Mutant 1 and Mutant 2 haploid strains to produce diploid cells. Using the table provided, **predict** whether the diploid cells will grow on each of the four media. Use a plus sign (+) to indicate growth and a minus sign (–) to indicate no growth.

Prediction (1 Point)

- There will be growth (+) in all four cells of the fourth column.

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Question 7

A researcher is studying patterns of gene expression in mice. The researcher collected samples from six different tissues in a healthy mouse and measured the amount of mRNA from six genes. The data are shown in Figure 1.

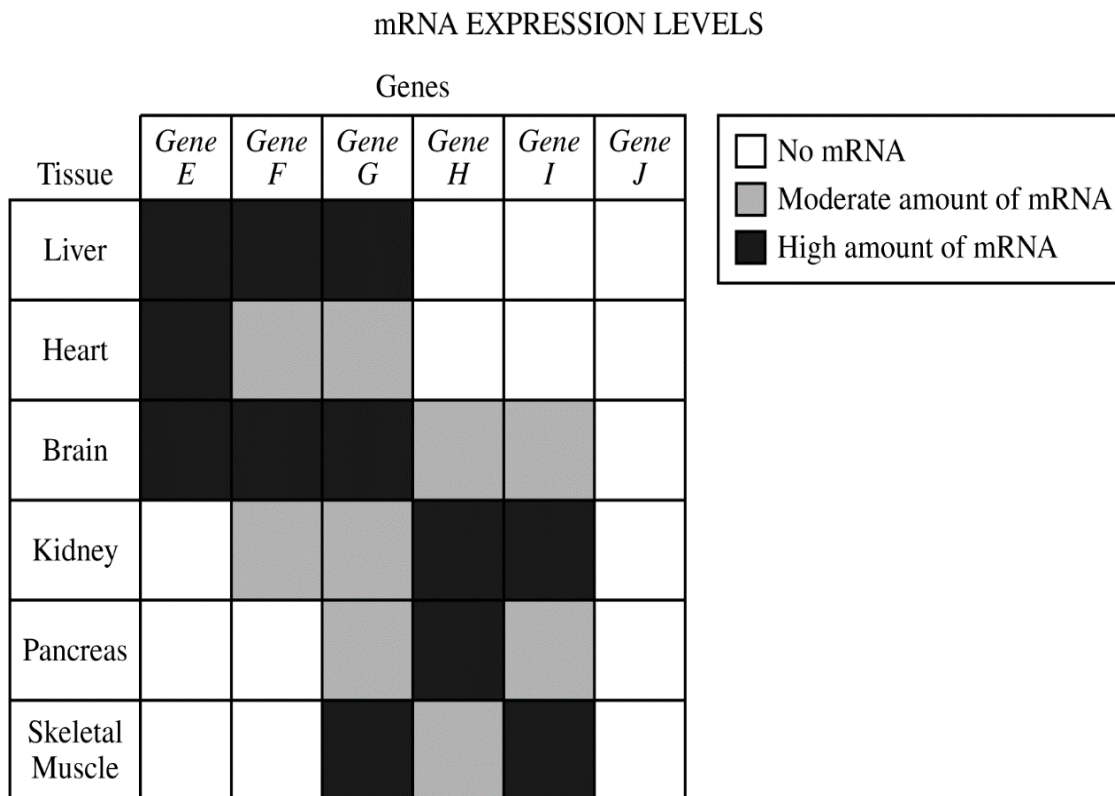


Figure 1. mRNA expression levels of six genes

(a) Based on the data provided, **identify** the gene that is most likely to encode a protein that is an essential component of glycolysis. **Provide reasoning** to support your identification.

Identification (1 point)

- *Gene G*

Reasoning (1 point)

- (*Gene G*) is the only gene expressed in all (six) tissues, AND glycolysis occurs in all (six) tissues.
- (*Gene G*) mRNA is the only mRNA present in all (six) tissues, AND glycolysis occurs in all (six) tissues.

(b) The researcher observed that tissues with a high level of *gene H* mRNA did not always have *gene H* protein. **Provide reasoning** to explain how tissues with high *gene H* mRNA levels can have no *gene H* protein.

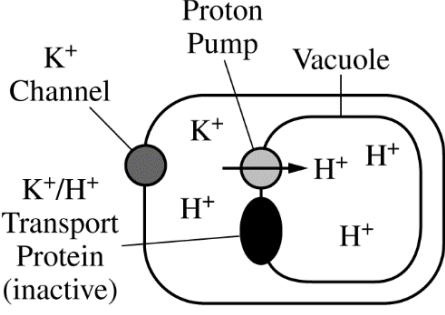
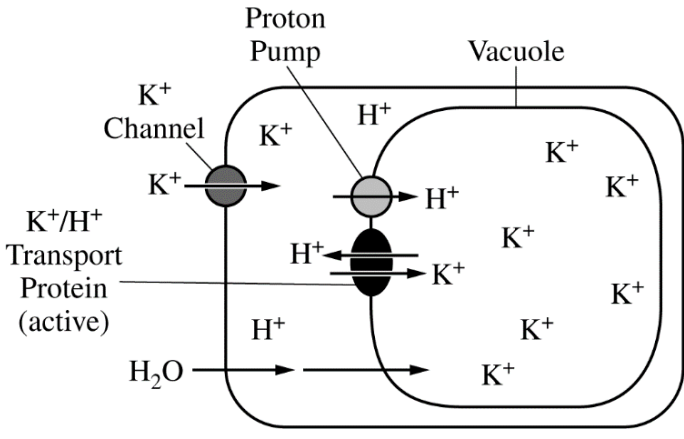
Reasoning (1 point)

- The mRNA is not exported from the nucleus.
- *Gene H* mRNA is not translated/RNA interference prevent(s) translation.
- Post-transcriptional modifications.

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Question 8

TABLE 1. CHANGES IN MORNING GLORY PETAL CELLS DURING FLOWER OPENING

	BUD	OPEN FLOWER
		
Vacuole pH	6.6	7.7
Flower Color	Red	Blue
Cell Volume	Small	Large

The petal color of the Mexican morning glory (*Ipomoea tricolor*) changes from red to blue, and the petal cells swell during flower opening. The pigment heavenly blue anthocyanin is found in the vacuole of petal cells. Petal color is determined by the pH of the vacuole. A model of a morning glory petal cell before and after flower opening is shown in Table 1.

(a) **Identify** the cellular component in the model that is responsible for the increase in the pH of the vacuole during flower opening AND **describe** the component's role in changing the pH of the vacuole.

Identification (1 point)

- (K^+ / H^+) transport protein

Description (1 point)

- It moves H^+ out of the vacuole.

(b) A researcher claims that the activation of the K^+ / H^+ transport protein causes the vacuole to swell with water. **Provide reasoning** to support the researcher's claim.

Reasoning (1 point)

- The concentration of solute (K^+) is increasing inside the vacuole.
- The solute (K^+) is moving into the vacuole, making it hypertonic/hyperosmotic/lowering water potential.

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AP Biology

Scoring Guidelines

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Question

TABLE 1. EFFECT OF 0.1 mM CAFFEINE ON MEMORY IN BEES

Treatment	Memory (average probability of revisiting a nectar source $\pm 2SE_{\bar{x}}$)	
	10 Minutes	24 Hours
Control	0.72 ± 0.09	0.41 ± 0.07
Caffeine	0.83 ± 0.07	0.78 ± 0.08

In flowering plants pollination is a process that leads to the fertilization of an egg and the production of seeds. Some flowers attract pollinators, such as bees, using visual and chemical cues. When a bee visits a flower, in addition to transferring pollen, the bee can take nectar from the flower and use it to make honey for the colony.

Nectar contains sugar, but certain plants also produce caffeine in the nectar. Caffeine is a bitter-tasting compound that can be toxic to insects at high concentrations. To investigate the role of caffeine in nectar, a group of researchers studied the effect of 0.1 mM caffeine on bee behavior. The results of an experiment to test the effect of caffeine on bees' memory of a nectar source are shown in Table 1.

On the axes provided, **construct** an appropriately labeled graph to illustrate the effect of caffeine on probability of bees revisiting a nectar source (memory). **(3 points)**

Construct graph (3 points)

- Correctly plotted means on a bar graph/modified bar graph
- Appropriate labels, units, and scaling
- Correctly plotted error bars

Based on the results, **describe** the effect of caffeine on each of the following: **(2 points)**

- Short-term (10 minute) memory of a nectar source
- Long-term (24 hour) memory of a nectar source

Description (2 points)

Short-term	Caffeine does not affect short-term memory/memory at 10 minutes.
Long-term	Caffeine improves/increases the long-term memory/memory at 24 hours.

Design an experiment using artificial flowers to investigate potential negative effects of increasing caffeine concentrations in nectar on the number of floral visits by bees. **Identify** the null hypothesis, an appropriate control treatment, and the predicted results that could be used to reject the null hypothesis. **(3 points)**

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Question continued)

Identification (3 points; 1 point per row)

Null hypothesis	Increasing caffeine concentration has no effect (on the number of floral visits by bees).
Control	(Nectar/flowers with) no caffeine
Predicted results	- The number of floral visits by bees is different at increasing caffeine concentrations. - The number of floral visits by bees is different than the control.

searchers found that nectar with caffeine tends to have a lower sugar content than nectar without caffeine. Plants use less energy to produce the caffeine in nectar than they do to produce the sugar in nectar. **Propose ONE benefit** to plants that produce nectar with caffeine and a lower sugar content. **Propose ONE cost** to bees that visit the flowers of plants that produce nectar with caffeine and a lower sugar content. **(2 points)**

Proposed plant benefit (1 point)

- More pollen is transferred/more visits by pollinators.
- Plants store energy/have more energy available for other uses.

Proposed bee cost (1 point)

- (Individual) bees visit more flowers.
- (Individual) bees use more energy.
- The colony/bees may produce less honey
- The colony/bees may produce lower quality honey/honey that provides less energy.

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Question 2

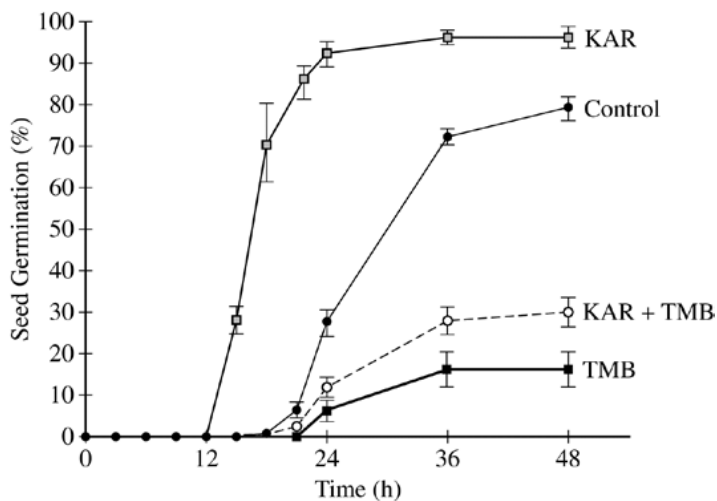


Figure 1. The effect of karrikins (KAR) and trimethylbutenolides (TMB) on seed germination in *Lactuca* plants. Error bars represent $\pm 2SE_{\bar{x}}$.

Fires frequently occur in some ecosystems and can destroy all above-ground vegetation. Many species of plants in these ecosystems respond to compounds in smoke that regulate seed germination after a major fire. Karrikins (KAR) and trimethylbutenolides (TMB) are water-soluble compounds found in smoke that are deposited in the soil as a result of a fire. KAR and TMB bind to receptor proteins in a seed. In a study on the effects of smoke on seeds, researchers recorded the timing and percent of seed germination in the presence of various combinations of KAR and TMB. The results are shown in Figure 1.

In a second investigation into the effect of available water on seed germination after a fire, researchers treated seeds with KAR or TMB. The treated seeds were then divided into two treatment groups. One group received a water rinse and the other group received no water rinse. The seeds were then incubated along with a group of control seeds that were not treated. The results are shown in the table.

EFFECT OF CHEMICAL TREATMENT AND WATER RINSE ON GERMINATION

Treatment Group	Chemical Treatment		Water Rinse	Germination Result
	KAR	TMB		
1 (control)	–	–	–	Control result
2	+	–	–	Different from control
3	–	+	–	Different from control
4 (control)	–	–	+	Control result
5	+	–	+	Different from control
6	–	+	+	Same as control

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Question 2 (continued)

(a) The researchers made the following claims about the effect of KAR and the effect of TMB on seed germination relative to the control treatment.

- KAR alone affects the timing of seed germination.
- KAR alone affects the percentage of seeds that germinate.
- TMB alone affects the timing of seed germination.
- TMB alone affects the percentage of seeds that germinate.

Provide support using data from Figure 1 for each of the researchers' claims. **(4 points)**

Claim	Support (1 point each row; 4 points maximum)
KAR affects timing	• germination starts earlier/sooner/faster/quicker
KAR affects percentage	• higher percentage of seeds germinate in the presence of only KAR
TMB affects timing	• germination starts later/slower
TMB affects percentage	• lower percentage of seeds germinate in presence of only TMB

(b) **Make a claim** about the effect of rinsing on the binding of KAR to the receptor in the seed and about the effect of rinsing on the binding of TMB to the receptor in the seed. Identify the appropriate treatment groups and results from the table that, when compared with the controls, **provide support** for each claim. **(4 points)**

Claim (2 points maximum; 1 point for KAR; 1 for TMB)	Support (2 points maximum; 1 point for KAR; 1 for TMB)				
• KAR remains (bound after rinsing) • Rinsing does not affect KAR (binding)	KAR with no rinse	KAR with rinse	different than	Controls	
	Group 2	Group 5		Group 1	Group 4
• TMB does not remain (bound) • Rinsing affects TMB (binding)	TMB with no rinse		different than	Control	
	Group 3			Group 1	
	TMB with rinse		same as	Control	
	Group 6			Group 4	

(c) There is intense competition by plants to successfully colonize areas that have been recently cleared by a fire. **Describe** ONE advantage of KAR regulation and ONE advantage of TMB regulation to plants that live in an ecosystem with regular fires. **(2 points)**

Description (1 point per row; 2 points maximum)	
Advantage of KAR regulation	• Germination occurs at times of increased resources availability. • Plants with KAR regulation can outcompete other plants (without KAR regulation). • Germination occurs when fewer competitors are present/land is barren.
Advantage of TMB regulation	• Plants with TMB regulation do not germinate/can maintain seed dormancy until (enough) water is available. • Plants with TMB regulation do not germinate in a dry environment.

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Question 3

Gibberellin is the primary plant hormone that promotes stem elongation. GA 3-beta-hydroxylase (GA3H) is the enzyme that catalyzes the reaction that converts a precursor of gibberellin to the active form of gibberellin. A mutation in the *GA3H* gene results in a short plant phenotype. When a pure-breeding tall plant is crossed with a pure-breeding short plant, all offspring in the F_1 generation are tall. When the F_1 plants are crossed with each other, 75 percent of the plants in the F_2 generation are tall and 25 percent of the plants are short.

		Second Base in Codon				
		U	C	A	G	
First Base in Codon	U	UUU } Phe UUC } UUA } Leu UUG }	UCU } UCC } Ser UCA } UCG }	UAU } Tyr UAC } UAA Stop UAG Stop	UGU } Cys UGC } UGA Stop UGG Trp	U C A G
	C	CUU } CUC } Leu CUA } CUG }	CCU } CCC } Pro CCA } CCG }	CAU } His CAC } CAA Gln CAG }	CGU } CGC } Arg CGA } CGG }	U C A G
	A	AUU } Ile AUC } AUA } AUG Met or Start	ACU } ACC } Thr ACA } ACG }	AAU } Asn AAC } AAA Lys AAG }	AGU } Ser AGC } AGA } Arg AGG }	U C A G
	G	GUU } Val GUC } GUA } GUG }	GCU } GCC } Ala GCA } GCG }	GAU } Asp GAC } GAA Glu GAG }	GGU } GGC } Gly GGA } GGG }	U C A G
						Third Base in Codon

Figure 1. The universal genetic code

- (a) The wild-type allele encodes a GA3H enzyme with alanine (Ala), a nonpolar amino acid, at position 229. The mutant allele encodes a GA3H enzyme with a threonine (Thr), a polar amino acid, at position 229.

Describe the effect of the mutation on the enzyme and **provide reasoning** to support how this mutation results in a short plant phenotype in homozygous recessive plants. (2 points)

Description (1 point)	Reasoning (1 point)
The amino acid substitution changes the shape/structure/function of the protein.	The mutation decreases/eliminates gibberellin production.

- (b) Using the codon chart provided, **predict** the change in the codon sequence that resulted in the substitution of alanine for threonine at amino acid position 229. (1 point)

Prediction (1 point maximum)

- $G \leftrightarrow A$ in the first position (of the codon)
- $5'\text{-GCN-}3' \leftrightarrow 5'\text{-ACN-}3'$
- $5'\text{-NGC-}3' \leftrightarrow 5'\text{-NGT-}3'$ in the template strand of DNA

- (c) **Describe** how individuals with one (heterozygous) or two (homozygous) copies of the wild-type *GA3H* allele can have the same phenotype. (1 point)

Description (1 point)

- Enough active enzyme is produced from one wild-type/dominant allele.
- Enough gibberellin is produced in the presence of one wild-type/dominant allele.

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Question 4

DIETARY COMPOSITION OF ORGANISMS IN AN AQUATIC ECOSYSTEM

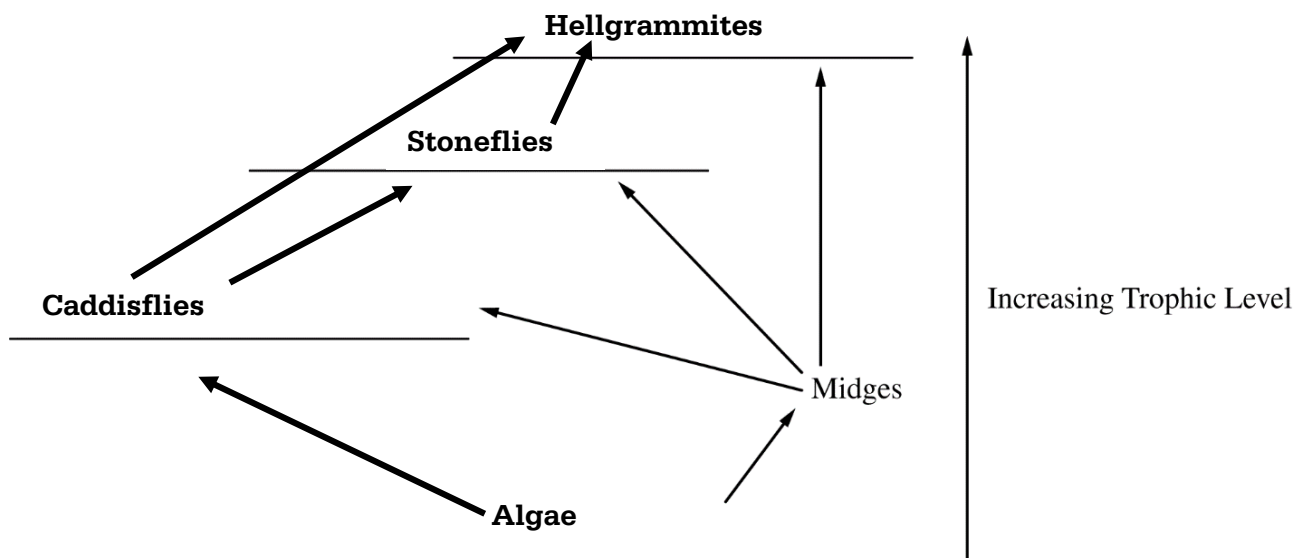
Organism	Food Source (% of diet)				
	Algae	Stoneflies	Midges	Hellgrammites	Caddisflies
Algae					
Stoneflies			90		10
Midges	100				
Hellgrammites		20	10		70
Caddisflies	70		30		

The table above shows how much each organism in an aquatic ecosystem relies on various food sources. The rows represent the organisms in the ecosystem, and the columns represent the food source. The percentages indicate the proportional dietary composition of each organism. High percentages indicate strong dependence of an organism on a food source.

- (a) Based on the food sources indicated in the data table, **construct** a food web in the template below. Write the organism names on the appropriate lines AND draw the arrows necessary to indicate the energy flow between organisms in the ecosystem. **(2 points)**

Construction of food web (2 points maximum)

- All four organisms placed on the appropriate lines
- All four arrows correctly drawn between organisms



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Question 4 (continued)

- (b) In an effort to control the number of midges, an area within the ecosystem was sprayed with the fungus *Metarhizium anisopliae*, which significantly decreased the midge population. Based on the data in the table, **predict** whether the spraying of the fungus will have the greatest short-term impact on the population of the stoneflies, the caddisflies, or the hellgrammites. **Justify** your prediction. (2 points)

Prediction (1 point)

- Stoneflies

Justification (1 point)

- Stoneflies have a higher dependence on the midges than do the hellgrammites and caddisflies.
- Midges are 90 percent of the stonefly diet, while 30 percent of the caddisfly and 10 percent of the hellgrammite diet are midges.

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Question 5

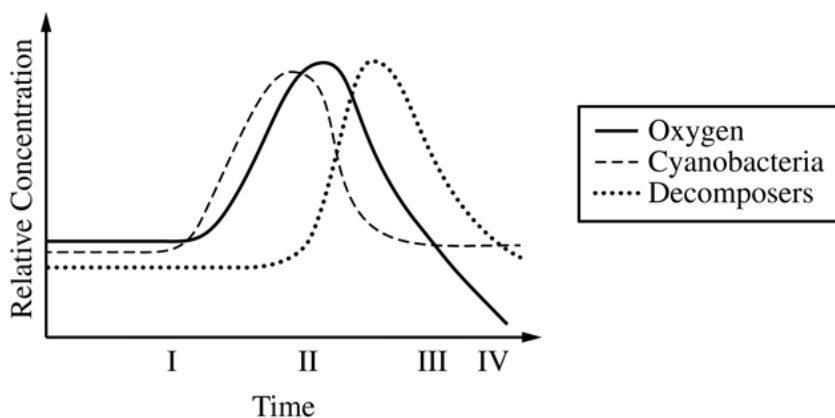


Figure 1. Characteristics of a pond community over time

Microcystis aeruginosis is a freshwater photosynthetic cyanobacterium. When temperatures increase and nutrients are readily available in its pond habitat, *M. aeruginosis* undergoes rapid cell division and forms an extremely large, visible mass of cells called an algal bloom. *M. aeruginosis* has a short life span and is decomposed by aerobic bacteria and fungi. **Identify** the metabolic pathway and the organism that is primarily responsible for the change in oxygen level in the pond between times I and II AND between times III and IV.

Identification (2 points per row; 4 points maximum)

Time Period	Metabolic pathway (1 point per box)	Organism (1 point per box)
I – II	Photosynthesis	Cyanobacteria (<i>M. aeruginosis</i>)
III – IV	Cellular respiration	Decomposers/fungi/bacteria

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Question 6

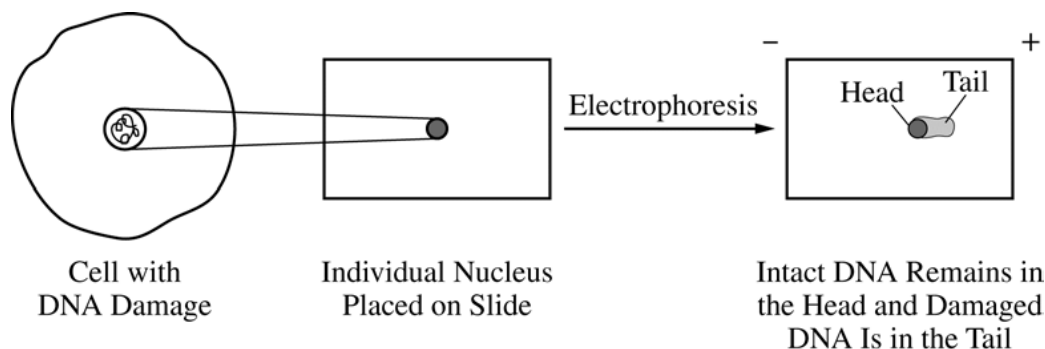


Figure 1. Comet assay to detect double-stranded breaks in DNA

A comet assay is a technique used to determine the amount of double-strand breaks in DNA (DNA damage) in cells. The nucleus of an individual cell is placed on a microscope slide coated with an agarose gel. An electric current is applied to the gel that causes DNA to move (electrophoresis), and the DNA is stained with a fluorescent dye. When viewed using a microscope, undamaged DNA from the nucleus appears as a round shape (the head), and the fragments of damaged DNA extend out from the head (the tail). The length of the tail corresponds to the amount of the damage in the DNA (see Figure 1).

- (a) To explain the movement of DNA fragments in the comet assay, **identify** one property of DNA and **provide reasoning** to support how the property contributes to the movement during the comet assay technique. **(2 points; both points must be earned from the same row.)**

Identification (1 point)	Reasoning (1 point)
DNA has a (negative) charge.	DNA moves toward the positive/oppositely charged pole.
DNA can be different sizes.	(Different size DNA fragments) move at different rates.

- (b) In a different experiment, cells are treated with a chemical mutagen that causes only nucleotide substitutions in DNA. **Predict** the likely results of a comet assay for this treatment. **(1 point)**

Prediction (1 point)

- Head (only) OR (head with) no tail.
- Tail will be shorter than a cell with double-stranded breaks in DNA.

2017 SCORING GUIDELINES

Question 7

Many species of bacteria grow in the mouths of animals and can form biofilms on teeth (plaque). Within plaque, the outer layers contain high levels of oxygen and the layers closest to the tooth contain low levels of oxygen. The surface of the tooth is covered in a hard layer of enamel, which can be dissolved under acidic conditions. When the enamel breaks down, the bacteria in plaque can extract nutrients from the tooth and cause cavities.

Certain types of bacteria (e.g., *Streptococcus mutans*) thrive in the innermost anaerobic layers of the plaque and are associated with cavities. Other types of bacteria (*Streptococcus sanguinis*) compete with *S. mutans* but are unable to thrive in acidic environments.

- (a) **Identify** the biochemical pathway *S. mutans* uses for metabolizing sugar and **describe** how the pathway contributes to the low pH in the inner layers of plaque. **(2 points; both points must be earned from the same row.)**

Identification	Description
fermentation	(lactic) acid/lactate
anaerobic respiration	acid
glycolysis	(pyruvic) acid/pyruvate

- (b) Normal tooth brushing effectively removes much of the plaque from the flat surfaces of teeth but cannot reach the surfaces between teeth. Many commercial toothpastes contain alkaline components, which raise the pH of the mouth. **Predict** how the population sizes of *S. mutans* AND *S. sanguinis* in the bacterial community in the plaque between the teeth are likely to change when these toothpastes are used. **(1 point)**

Prediction (1 point)

- S. mutans* decreases AND *S. sanguinis* increases

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Question 8

Estrogens are small hydrophobic lipid hormones that promote cell division and the development of reproductive structures in mammals. Estrogens passively diffuse across the plasma membrane and bind to their receptor proteins in the cytoplasm of target cells.

- (a) **Describe** ONE characteristic of the plasma membrane that allows estrogens to passively cross the membrane. **(1 point)**

Description (1 point)

- Hydrophobic/nonpolar
- Space between phospholipids

- (b) In a laboratory experiment, a researcher generates antibodies that bind to purified estrogen receptors extracted from cells. The researcher uses the antibodies in an attempt to treat estrogen-dependent cancers but finds that the treatment is ineffective. **Explain** the ineffectiveness of the antibodies for treating estrogen-dependent cancers. **(2 points)**

Explanation (2 points)

- Antibodies are unable to enter the cell.
- (Extracellular) antibodies will not bind to (intracellular) estrogen receptors.

AP[®] Biology

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Question 1

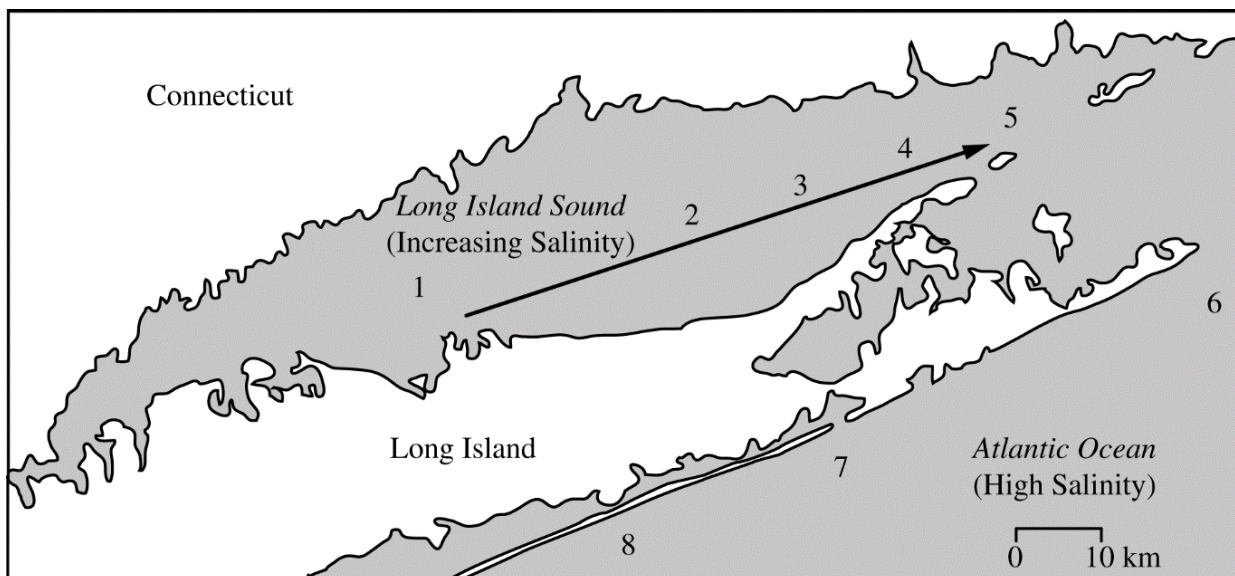


Figure 1. Sampling sites of marine mussels at various locations (1-8) in Long Island Sound and the Atlantic Ocean

TABLE 1. PERCENT OF INDIVIDUALS POSSESSING *lap*⁹⁴ ALLELE

	Long Island Sound					Atlantic Ocean		
Site	1	2	3	4	5	6	7	8
<i>lap</i> ⁹⁴ frequency (%)	13	16	25	37	55	59	59	59
Salinity	Low $\longrightarrow$ High					High		

Leucine aminopeptidases (LAPs) are found in all living organisms and have been associated with the response of the marine mussel, *Mytilus edulis*, to changes in salinity. LAPs are enzymes that remove N-terminal amino acids from proteins and release the free amino acids into the cytosol. To investigate the evolution of LAPs in wild populations of *M. edulis*, researchers sampled adult mussels from several different locations along a part of the northeast coast of the United States, as shown in Figure 1. The researchers then determined the percent of individuals possessing a particular *lap* allele, *lap*⁹⁴, in mussels from each sample site (table 1).

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Question 1 (continued)

- (a) On the axes provided, **construct** an appropriately labeled bar graph to illustrate the observed frequencies of the *lap*⁹⁴ allele in the study populations. **(3 points)**

Construct graph (3 points)

- Correctly plotted bar graph that accurately represents the trend
- Correct axis labeling
- Correct scale and units

- (b) Based on the data, **describe** the most likely effect of salinity on the frequency of the *lap*⁹⁴ allele in the marine mussel populations in Long Island Sound. **Predict** the likely *lap*⁹⁴ allele frequency at a sampling site between site 1 and site 2 in Long Island Sound. **(2 points)**

Description (1 point)	Prediction (1 point)
• As salinity increases <i>lap</i>⁹⁴ frequency increases • As salinity decreases <i>lap</i>⁹⁴ frequency decreases	Between 13 and 16 percent (or a selected value between 13 and 16 percent)

- (c) **Describe** the most likely effect of LAP⁹⁴ activity on the osmolarity of the cytosol. **Describe** the function of LAP⁹⁴ in maintaining water balance in the mussels living in the Atlantic Ocean. **(2 points)**

Describe effect of LAP ⁹⁴ activity (1 point)	Describe function of LAP ⁹⁴ in maintaining water balance (1 point)
• LAP⁹⁴ increases osmolarity/solute concentration of the cytosol • LAP⁹⁴ decreases water potential of the cytosol	Prevents water loss to the environment

- (d) Marine mussel larvae are evenly dispersed throughout the study area by water movement. As larvae mature, they attach to the rocks in the water. **Explain** the differences in *lap*⁹⁴ allele frequency among adult mussel populations at the sample sites despite the dispersal of larvae throughout the entire study area. **Predict** the likely effect on distribution of mussels in Long Island Sound if the *lap*⁹⁴ allele was found in all of the mussels in the population. **Justify** your prediction. **(3 points)**

Explanation (1 point)	Prediction (1 point)	Justification (1 point)
• Mussels with <i>lap</i>⁹⁴ allele are more likely to survive in high salinity/less likely to survive in low salinity. • Mussels without <i>lap</i>⁹⁴ allele are less likely to survive in high salinity/more likely to survive in low salinity.	• Mussel population will increase in high salinity. • Mussel population will decline in low salinity.	• Mussels in high salinity with <i>lap</i>⁹⁴ allele will osmoregulate. • Mussels in low salinity with <i>lap</i>⁹⁴ allele will not osmoregulate.

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Question 2

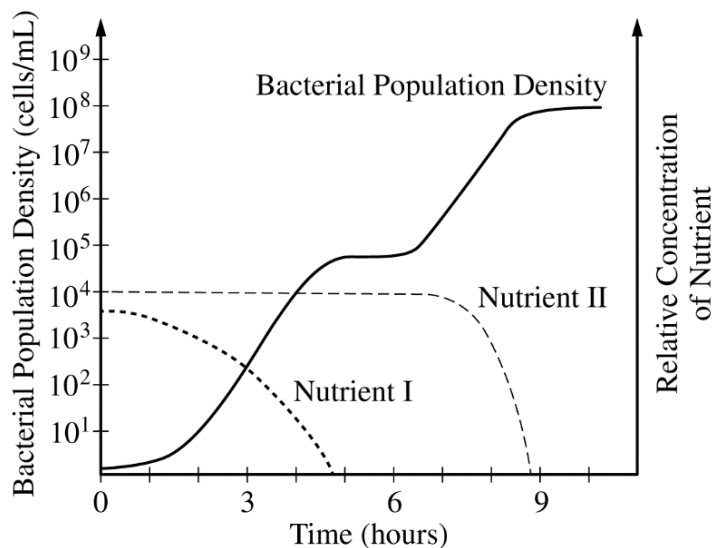


Figure 1. Bacterial population growth in the presence of two nutrients (nutrient I and nutrient II)

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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Question 3

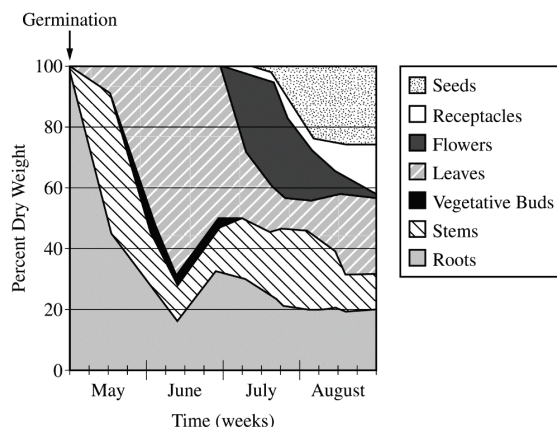


Figure 1. Percent dry weight of different plant structures during the growing season for an annual plant

The graph above illustrates the percent dry weight of different parts of a particular annual plant (plants that live less than one year) from early May to late August. The percent dry weight can be used to estimate the amount of energy a plant uses to produce its leaves, vegetative buds, stems, roots, and reproductive parts (seeds, receptacles, and flowers).

- (a) **Identify** the direct source of the energy used for plant growth during the first week of May, and **identify** the part of the plant that grew the most during the same period. **(2 points)**

Identify direct source of energy (1 point)

- Seed
- Stored organic nutrients/carbohydrates

Identify plant part (1 point)

- Roots

- (b) Based on the data on the graph, **estimate** the percent of the total energy that the plant has allocated to the growth of leaves on the first day of July. **(1 point)**

Identification (1 point)

- Any value between 45-55 percent

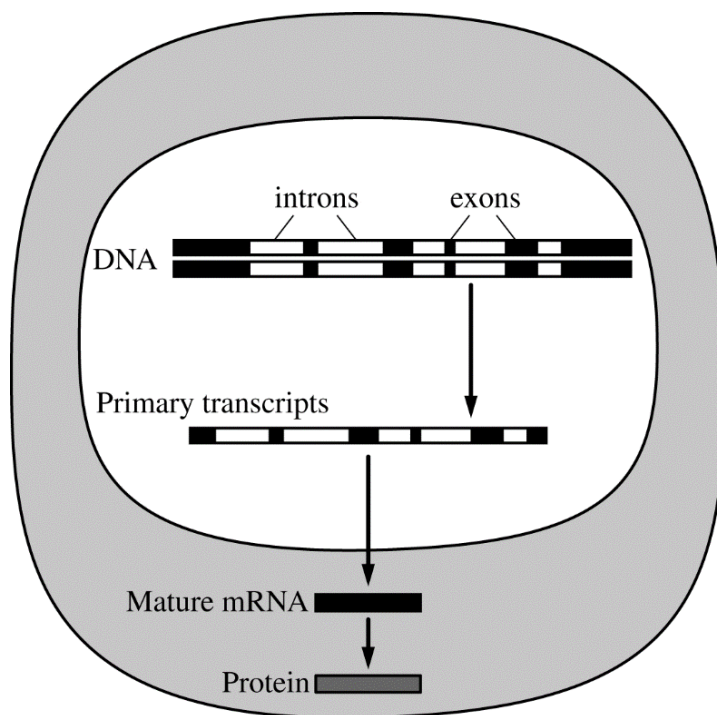
- (c) Compared with perennials (plants that live more than two years), annual plants often allocate a much greater percentage of their total energy to growth of their reproductive parts in any given year. **Propose** ONE evolutionary advantage of the energy allocation strategy in annual plants compared with that in perennial plants. **(1 point)**

Proposed advantage (1 point)

- Increased chance of reproduction before the plants die.
- If the plants do not use the strategy, they decrease the likelihood they will ever reproduce.

2016 SCORING GUIDELINES

Question 4



The figure represents the process of expression of gene *X* in a eukaryotic cell.

- (a) The primary transcript in the figure is 15 kilobases (kb) long, but the mature mRNA is 7 kb in length.

Describe the modification that most likely resulted in the 8 kb difference in length of the mature mRNA molecule. **Identify** in your response the location in the cell where the change occurs.

(2 points)

Describe process (1 point)

- Removal of introns
- RNA processing

Identification (1 point)

- Nucleus

- (b) **Predict** the length of the mature gene *X* mRNA if the full-length gene is introduced and expressed in prokaryotic cells. **Justify** your prediction. (2 points)

Prediction (1 point)

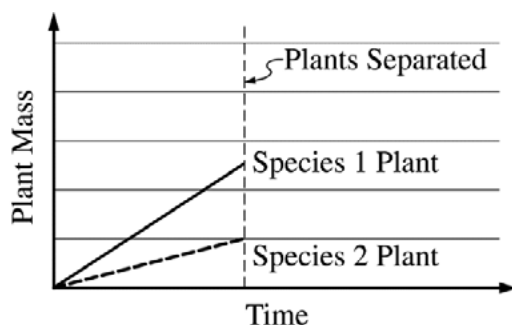
- 15 kb
- Longer than the mature mRNA in the eukaryote

Justification (1 point)

- mRNA processing typically does not occur in prokaryotes

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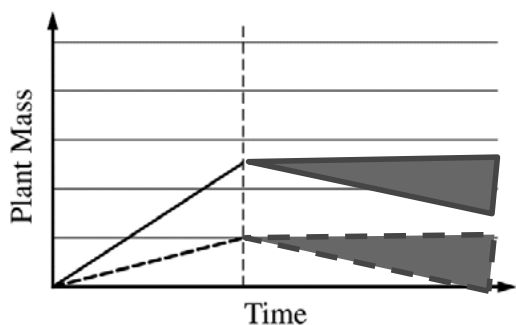
Question 5



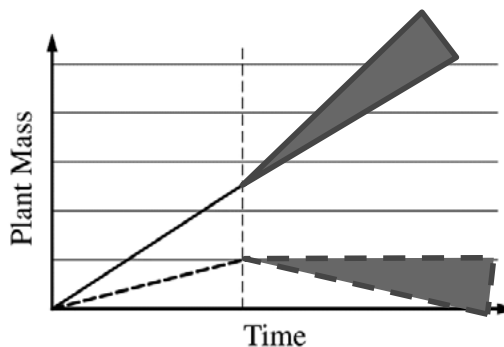
The graph above shows the mass of plants from two different species over time. The plants grew while attached to each other. The plants were separated at the time indicated by the vertical line in the graph.

Using template 1, **graph** the predicted shape of the plant-mass lines after separation of the two plants if the plants were in an obligate mutualistic relationship. On template 2, **graph** the predicted shape of the plant-mass lines if the species 2 plant was a parasite of the species 1 plant. **Justify** each of your predictions. (4 points)

TEMPLATE 1: OBLIGATE MUTUALISM



TEMPLATE 2: PARASITISM



	Graph characteristics (1 point each graph; 2 points maximum)	Justification (1 point each box; 2 points maximum)
Obligate Mutualism	Both of the growth curves level off or decline.	- Each species depends on the other for survival. - Without the relationship, both species are harmed.
Parasitism	Species 1 continues to increase while species 2 levels off or declines.	- The parasite requires an association with the host to survive but harms the host. - Without the relationship, the parasite cannot survive while the host continues to grow.

2016 SCORING GUIDELINES

Question 6

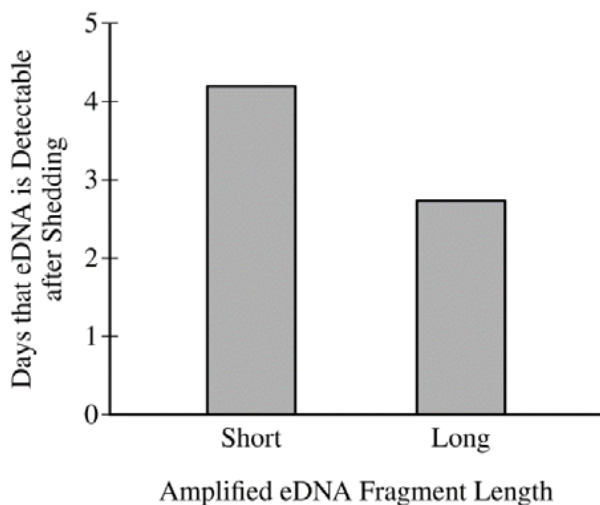


Figure 1. Detectability of eDNA fragments of varying lengths

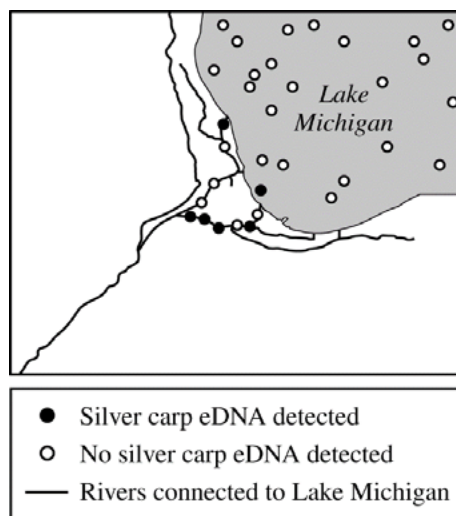


Figure 2. Map of the waterways that connect a nearby river system to Lake Michigan

Living and dead organisms continuously shed DNA fragments, known as eDNA, into the environment. To detect eDNA fragments in the environment, the polymerase chain reaction (PCR) can be used to amplify specific eDNA fragments. eDNA fragments of different lengths persist in the environment for varying amounts of time before becoming undetectable (Figure 1).

To investigate whether silver carp, an invasive fish, have moved from a nearby river system into Lake Michigan, researchers tested water samples for the presence of eDNA specific to silver carp (Figure 2).

- (a) **Justify** the use of eDNA sampling as an appropriate technique for detecting the presence of silver carp in an environment where many different species of fish are found. **Propose** ONE advantage of identifying long eDNA fragments as opposed to short fragments for detecting silver carp. **(2 points)**

Justify (1 point)

- eDNA allows detection of the fish without visual identification/catching the fish.

Proposed advantage (1 point)

- Longer fragments indicate more recent presence of fish.
- Longer fragments are more likely to contain a sequence that is specific to silver carp.
- Longer sequences/more base pairs may increase accuracy/specificity/confidence that the eDNA is from a silver carp and not a related species.

- (b) The researchers tested a large number of water samples from Lake Michigan and found eDNA specific to silver carp in a single sample in the lake, as indicated in Figure 2. The researchers concluded that the single positive sample was a false positive and that no silver carp had entered Lake Michigan.

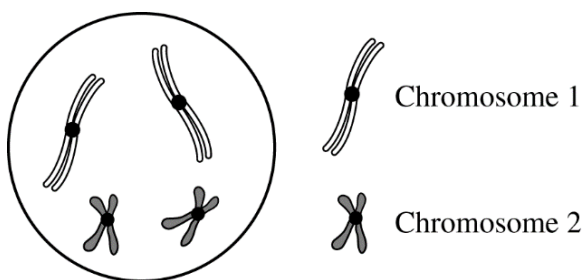
Provide reasoning other than human error to support the researchers' claim. **(1 point)**

Reasoning (1 point)

- eDNA entered the lake by means other than the fish (e.g., river flow, boats, waste from predators).

2016 SCORING GUIDELINES

Question 7

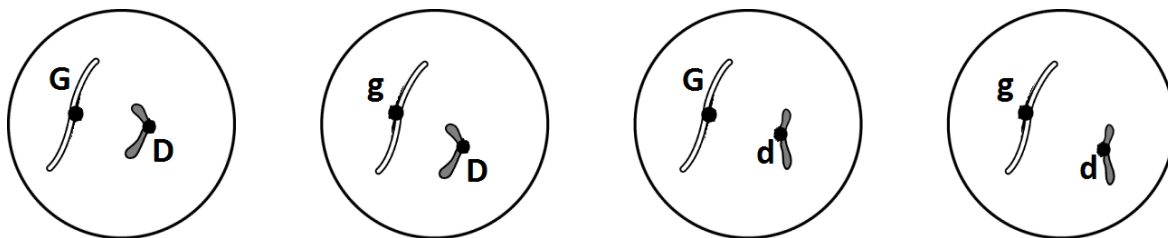


In a certain species of plant, the diploid number of chromosomes is 4 ($2n = 4$). Flower color is controlled by a single gene in which the green allele (G) is dominant to the purple allele (g). Plant height is controlled by a different gene in which the dwarf allele (D) is dominant to the tall allele (d). Individuals of the parental (P) generation with the genotypes $GGDD$ and $ggdd$ were crossed to produce F_1 progeny.

- (a) **Construct** a diagram below to depict the four possible normal products of meiosis that would be produced by the F_1 progeny. Show the chromosomes and the allele(s) they carry. Assume the genes are located on different chromosomes and the gene for flower color is on chromosome 1. **(1 point)**

Construct diagram (1 point)

- Diagram must include all of the following:
 - Each cell has one unduplicated chromosome 1 (with G or g).
 - Each cell has one unduplicated chromosome 2 (with D or d).
 - Genotype combinations should be: GD , Gd , gD , gd .



- (b) **Predict** the possible phenotypes and their ratios in the offspring of a testcross between an F_1 individual and a $ggdd$ individual. **(1 point)**

Prediction (1 point)

- 1 green dwarf: 1 green tall: 1 purple dwarf: 1 purple tall

- (c) If the two genes were genetically linked, **describe** how the proportions of phenotypes of the resulting offspring would most likely differ from those of the testcross between an F_1 individual and a $ggdd$ individual. **(1 point)**

Identify difference (1 point)

- The majority/greater than 50 percent would have the parental plant phenotypes
- Greater than 25 percent would be green dwarf plants and greater than 25 percent would be purple tall plants
- Less than 25 percent would be green tall plants and less than 25 percent would be purple dwarf plants

2016 SCORING GUIDELINES

Question 8

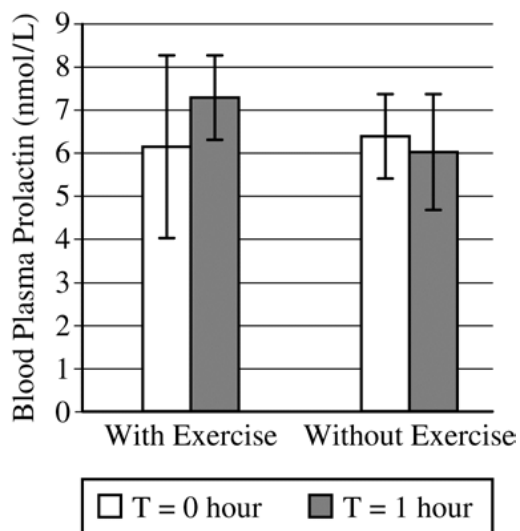


Figure 1. Effect of exercise on blood prolactin levels in adult males. The data represent the mean $\pm 2SE_{\bar{x}}$.

Researchers conducted a study to investigate the effect of exercise on the release of prolactin into the blood. The researchers measured the concentration of prolactin in the blood of eight adult males before (T = 0 hour) and after one hour (T = 1 hour) of vigorous exercise. As a control, the researchers measured the concentration of blood prolactin in the same group of individuals at the same times of day one week later, but without having them exercise. The results are shown in Figure 1.

- (a) **Justify** the use of the without-exercise treatment as the control in the study design. **(1 point)**

Justification (1 point)

- Attribute changes in the concentration of blood prolactin to exercise only
- Rule out normal fluctuations in prolactin release/levels

- (b) Using evidence from the specific treatments, **determine** whether prolactin release changes after exercise. **Justify** your answer. **(2 points)**

Determination (1 point)

- Exercise does not affect prolactin release

Justification (1 point)

- The T=1 hour with-exercise mean and the T=1 hour without-exercise mean are within $\pm 2SE_{\bar{x}}$.
- The $\pm 2SE_{\bar{x}}$ error bars for the T=1 hour with-exercise time point and the T=1 hour time without-exercise point overlap.
- The $\pm 2SE_{\bar{x}}$ error bars for the T=0 and T=1 hour with-exercise time points overlap.
- The T=0 hour with-exercise mean and the T=1 hour with exercise-mean are within $\pm 2SE_{\bar{x}}$.

AP[®] Biology

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2015 SCORING GUIDELINES

Question 1

Many species have circadian rhythms that exhibit an approximately 24-hour cycle. Circadian rhythms are controlled by both genetics and environmental conditions, including light.

Researchers investigated the effect of light on mouse behavior by using a running wheel with a motion sensor to record activity on actograms, as shown in Figure 1.

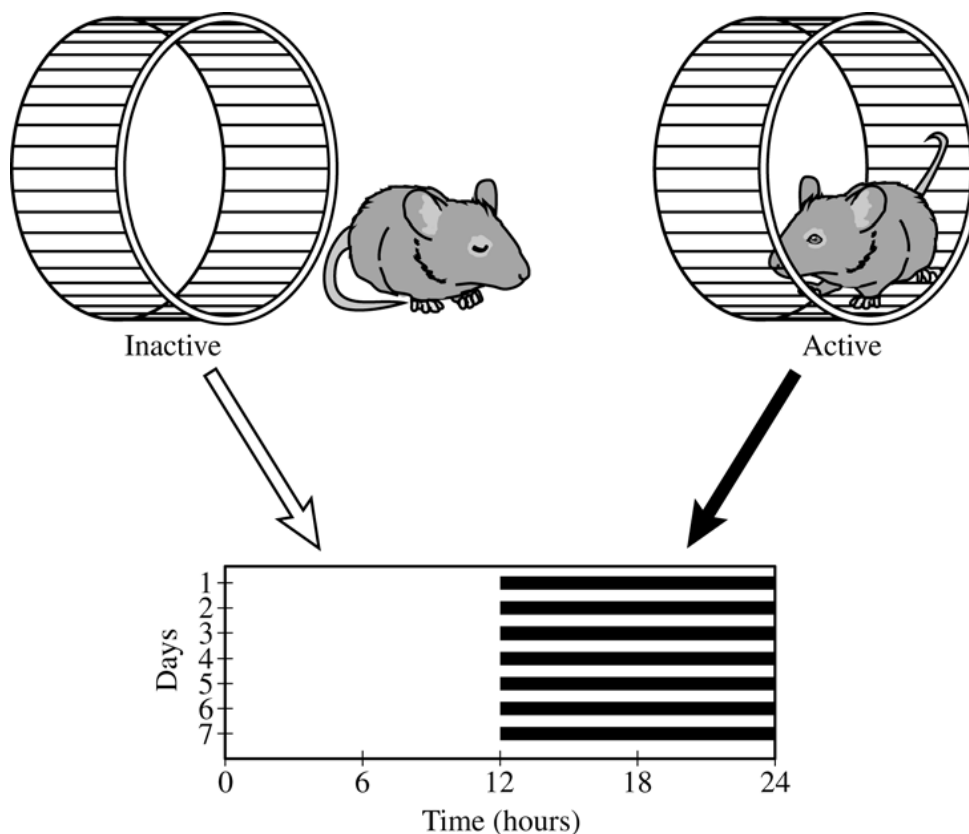


Figure 1. Strategy for recording mouse activity data. When a mouse is active on the running wheel, the activity is recorded as a dark horizontal line on an actogram. When the mouse is inactive, no dark line is recorded.

For the investigation, adult male mice were individually housed in cages in a soundproof room at 25°C. Each mouse was provided with adequate food, water, bedding material, and a running wheel. The mice were exposed to daily periods of 12 hours of light (L) and 12 hours of dark (D) (L12:D12) for 14 days, and their activity was continuously monitored. The activity data are shown in Figure 2.

2015 SCORING GUIDELINES

Question 1 (continued)

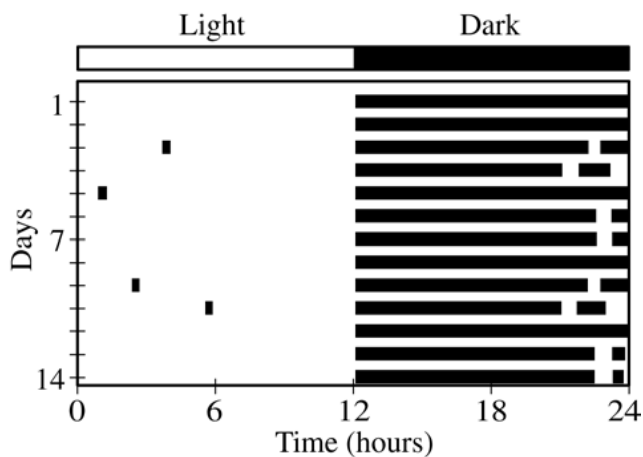


Figure 2. Actogram of mouse activity under L12:D12 conditions. Each row represents a 24-hour period, and the dark horizontal lines represent activity on the running wheel.

After 14 days in L12:D12, the mice were placed in continuous darkness (DD), and their activity on the running wheel was recorded as before. The activity data under DD conditions are shown in Figure 3.

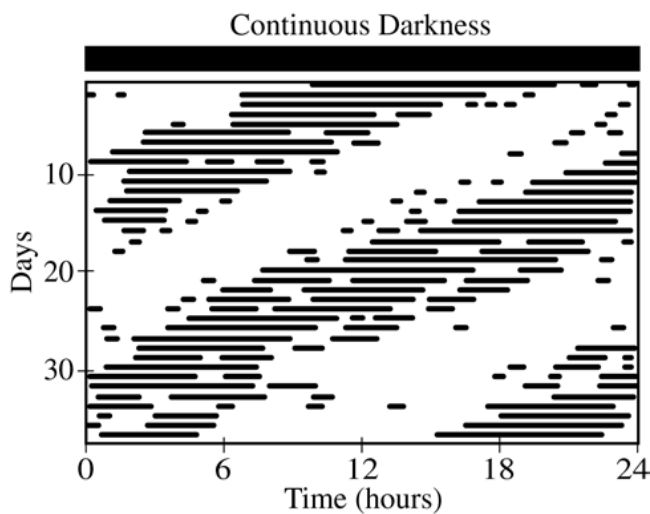


Figure 3. Actogram of mouse activity under DD conditions. Each row represents a 24-hour period, and the dark horizontal lines represent activity on the running wheel.

2015 SCORING GUIDELINES

Question 1 (continued)

- (a) The nervous system plays a role in coordinating the observed activity pattern of the mice in response to light-dark stimuli. **Describe** ONE role of each of the following anatomical structures in responding to light-dark stimuli.

- A photoreceptor in the retina of the eye
- The brain
- A motor neuron

	Descriptions (1 point per box; 3 points maximum)
Photoreceptor	Detects light/dark stimulus and initiates/transmits signal
Brain	Integrates/processes/coordinates information
Motor neuron	Transmits signal from brain to an effector

- (b) Based on an analysis of the data in Figure 2, **describe** the activity pattern of the mice during the light and dark periods of the L12:D12 cycle.

Description (1 point)

- Active during dark phase AND inactive during light phase
- Active ONLY during the dark period
- Inactive ONLY during the light period

- (c) The researchers claim that the genetically controlled circadian rhythm in the mice does not follow a 24-hour cycle. **Describe** ONE difference between the daily pattern of activity under L12:D12 conditions (Figure 2) and under DD conditions (Figure 3), and use the data to **support** the researchers' claim.

Description (1 point)

- Active period begins a little earlier each day
- Active/inactive period is shorter than 12 hours each day
- Daily circadian rhythm is less than 24 hours
- Pattern of activity shifts each day

Support (1 point)

- Without light, active/inactive periods are determined only by the genetically controlled circadian rhythm.
- If it were a 24-hour circadian rhythm, the pattern of activity in DD would be the same as the pattern of activity in L12:D12.

- (d) To investigate the claim that exposure to light overrides the genetically controlled circadian rhythm, the researchers plan to repeat the experiment with mutant mice lacking a gene that controls the circadian rhythm. **Predict** the observed activity pattern of the mutant mice under L12:D12 conditions and under DD conditions that would support the claim that light overrides the genetically controlled circadian rhythm.

2015 SCORING GUIDELINES

Question 1 (continued)

Conditions	Predicted Activity Pattern (1 point per box; 2 points maximum)
Mutant under L12:D12	Normal rhythm/rhythm similar to wild-type mouse under L12:D12 (Figure 2)
Mutant under DD	• Random activity throughout the 24 hour period • No pattern/rhythm • Constantly active/constantly inactive

- (e) In nature, mice are potential prey for some predatory birds that hunt during the day. **Describe** TWO features of a model that represents how the predator-prey relationship between the birds and the mice may have resulted in the evolution of the observed activity pattern of the mice.

	Description (1 point per box; 2 points maximum)
Selective Advantage	• Selection for individuals active at night • Selection against individuals active during the day • Day-active variants susceptible to predation • Night-active variants able to avoid predation
Reproductive Success	• Mice selected for produce more offspring • Mice selected against produce fewer offspring

2015 SCORING GUIDELINES

Question 2

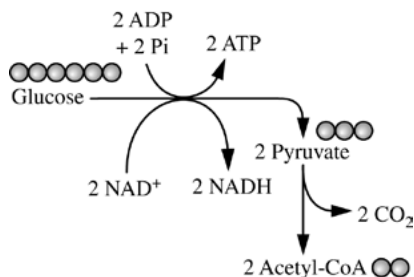


Figure 1. Glycolysis and pyruvate oxidation

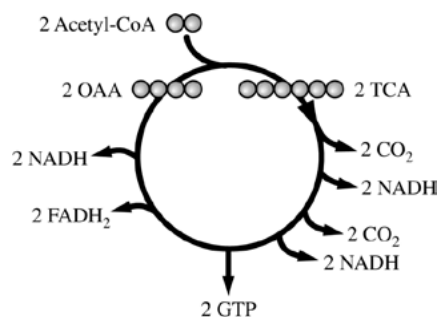


Figure 2. Krebs cycle

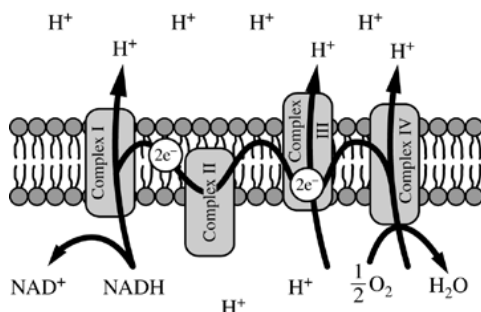


Figure 3. Electron transport chain

Cellular respiration includes the metabolic pathways of glycolysis, the Krebs cycle, and the electron transport chain, as represented in the figures. In cellular respiration, carbohydrates and other metabolites are oxidized, and the resulting energy-transfer reactions support the synthesis of ATP.

(a) Using the information above, **describe** ONE contribution of each of the following in ATP synthesis.

- Catabolism of glucose in glycolysis and pyruvate oxidation
- Oxidation of intermediates in the Krebs cycle
- Formation of a proton gradient by the electron transport chain

Process	Description (1 point each box; 3 points maximum)
Catabolism of glucose in glycolysis and pyruvate oxidation	• Produces NADH for use in ETC • Produces acetyl-CoA for entry into Krebs cycle • Provides energy for (substrate level) phosphorylation of ADP
Oxidation of intermediates in the Krebs cycle	• Produces NADH or FADH₂ for use in ETC • Releases high energy electrons for use in ETC • Provides energy to pump protons against their concentration gradient • Produces GTP for (substrate level) phosphorylation of ADP
Formation of a proton gradient by the electron transport chain	• The flow of protons through membrane-bound ATP synthase generates ATP • Provides energy for (oxidative) phosphorylation of ADP

2015 SCORING GUIDELINES

Question 2 (continued)

(b) Use each of the following observations to **justify** the claim that glycolysis first occurred in a common ancestor of all living organisms.

- Nearly all existing organisms perform glycolysis.
- Glycolysis occurs under anaerobic conditions.
- Glycolysis occurs only in the cytosol.

Observation	Justification (1 point each box; 3 points maximum)
Nearly all existing organisms perform glycolysis	• Trait/gene/process originated early and was inherited/passed down/highly conserved • Glycolysis provided a selective advantage that was passed on to descendants
Glycolysis occurs under anaerobic conditions	Origin of glycolysis pre-dates free atmospheric oxygen/photosynthesis
Glycolysis occurs only in the cytosol	Origin of glycolysis pre-dates cell types with membrane-bound organelles/eukaryotes/endosymbiosis

(c) A researcher estimates that, in a certain organism, the complete metabolism of glucose produces 30 molecules of ATP for each molecule of glucose. The energy released from the total oxidation of glucose under standard conditions is 686 kcal/mol. The energy released from the hydrolysis of ATP to ADP and inorganic phosphate under standard conditions is 7.3 kcal/mol. **Calculate** the amount of energy available from the hydrolysis of 30 moles of ATP. **Calculate** the efficiency of total ATP production from 1 mole of glucose in the organism. **Describe** what happens to the excess energy that is released from the metabolism of glucose.

	Calculation/description (1 point each box; 3 points maximum)
Calculate available energy in ATP	219 kcal
Calculate efficiency	0.31 - 0.32 or 31 - 32%
Describe fate of excess energy	Released as heat/increases entropy

(d) The enzymes of the Krebs cycle function in the cytosol of bacteria, but among eukaryotes the enzymes function mostly in the mitochondria. **Pose** a scientific question that connects the subcellular location of the enzymes in the Krebs cycle to the evolution of eukaryotes.

Question (1 point)

- A valid scientific question related to evolution of eukaryotes (e.g., Since the Krebs cycle occurs in the “cytoplasm” of the mitochondria (matrix), does it suggest that mitochondria were once prokaryotes?)

2015 SCORING GUIDELINES

Question 3

The amino-acid sequence of cytochrome *c* was determined for five different species of vertebrates. The table below shows the number of differences in the sequences between each pair of species.

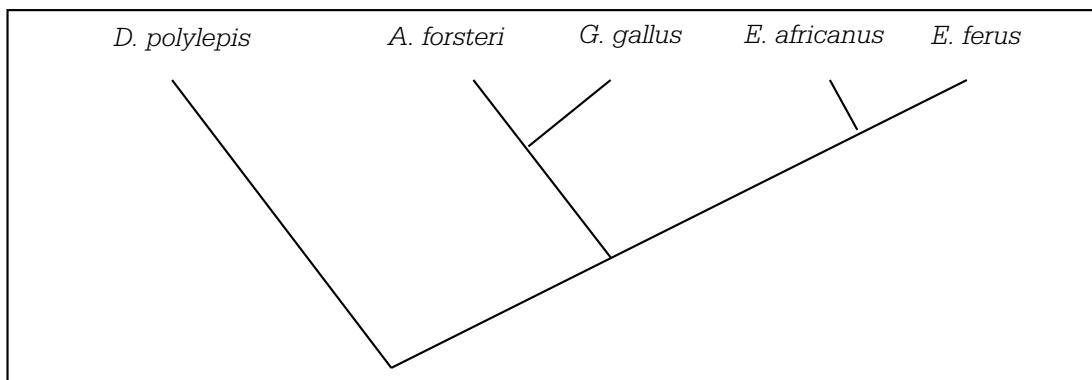
THE NUMBER OF AMINO ACID DIFFERENCES
IN CYTOCHROME *c* AMONG FIVE SPECIES

	<i>E. ferus</i>	<i>D. polylepis</i>	<i>G. gallus</i>	<i>A. forsteri</i>	<i>E. africanus</i>
<i>E. ferus</i>	0	21	11	13	1
<i>D. polylepis</i>		0	18	17	20
<i>G. gallus</i>			0	3	10
<i>A. forsteri</i>				0	12
<i>E. africanus</i>					0

- (a) Using the data in the table, **create** a phylogenetic tree on the template provided to reflect the evolutionary relationships of the organisms. **Provide reasoning** for the placement on the tree of the species that is least related to the others.

Phylogenetic tree (1 point)

NOTE: There can be free rotation around the nodes in the tree.



Reasoning (1 point)

- *D. polylepis* has the most differences in amino acids (or changes in DNA or proteins as they relate to amino acids).

- (b) **Identify** whether morphological data or amino acid sequence data are more likely to accurately represent the true evolutionary relationships among the species, and **provide reasoning** for your answer.

2015 SCORING GUIDELINES**Question 3 (continued)****Identification (1 point)**

- Amino acid/molecular data

Reasoning (1 point)

- Morphology may be similar (due to convergent evolution/analogous structures) even if there are differences in amino acid/DNA sequences.
- Molecular data (e.g. amino acid changes, DNA changes) directly show genetic make-up/ reveal evolution.

OR

Identification (1 point)

- Morphological data

Reasoning (1 point)

- Similar molecular sequences may result in different morphologies.
- An example of species with similar proteins but different morphology (e.g., chimps and humans).

2015 SCORING GUIDELINES

Question 4

Both mitosis and meiosis are forms of cell division that produce daughter cells containing genetic information from the parent cell.

- (a) **Describe** TWO events that are common to both mitosis and meiosis that ensure the resulting daughter cells inherit the appropriate number of chromosomes.

Description (1 point each; 2 points maximum)

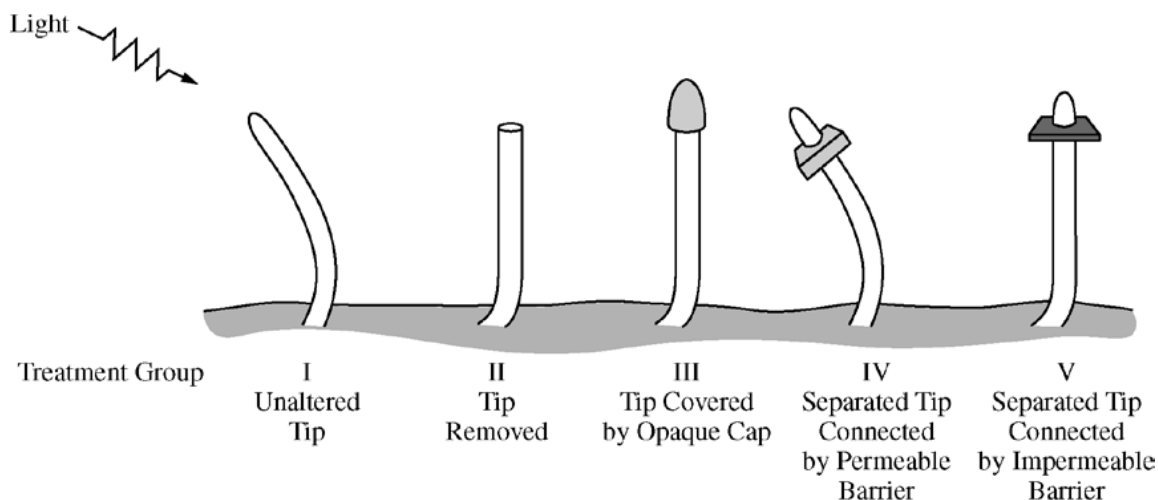
- Spindle elements (microtubules) form/attach to chromosomes
- Chromatin condenses
- Alignment of chromosomes across center of cell prior to chromosome separation
- Separation of chromatids/centromeres to daughter cells
- G2/M checkpoint occurs in both processes
- Replication or synthesis of DNA precedes mitosis/meiosis
- Cytokinesis separates daughter cells after mitosis/meiosis

- (b) The genetic composition of daughter cells produced by mitosis differs from that of the daughter cells produced by meiosis. **Describe** TWO features of the cell division processes that lead to these differences.

Feature	Description (1 point each row; 2 points maximum)	
	Mitosis	Meiosis
Number of divisions/ number of resulting cells	1 division/ 2 cells result	2 divisions/ 4 cells result
Ploidy of daughter cells	• Same as parent cell • Diploid • ($2n \rightarrow 2n$ or $n \rightarrow n$)	• Half of parent cell • Haploid • ($4n \rightarrow 2n$; $2n \rightarrow n$)
Chromatids separate	Occurs	Not in meiosis I/only in meiosis II
Crossing over	Does not occur	Occurs
Homologous chromosomes separate/independently assort	Does not occur	Occurs

2015 SCORING GUIDELINES

Question 5



Phototropism in plants is a response in which a plant shoot grows toward a light source. The results of five different experimental treatments from classic investigations of phototropism are shown above.

- (a) **Give support** for the claim that the cells located in the tip of the plant shoot detect the light by comparing the results from treatment group I with the results from treatment group II and treatment group III.

Support (2 points maximum)

- In treatment II the tip is removed and the plant no longer bends toward light.
- In treatment III the cap blocks the light to the tip and the plant no longer bends toward light.

- (b) In treatment groups IV and V, the tips of the plants are removed and placed back onto the shoot on either a permeable or impermeable barrier. Using the results from treatment groups IV and V, **describe** TWO additional characteristics of the phototropism response.

Description (2 points maximum)

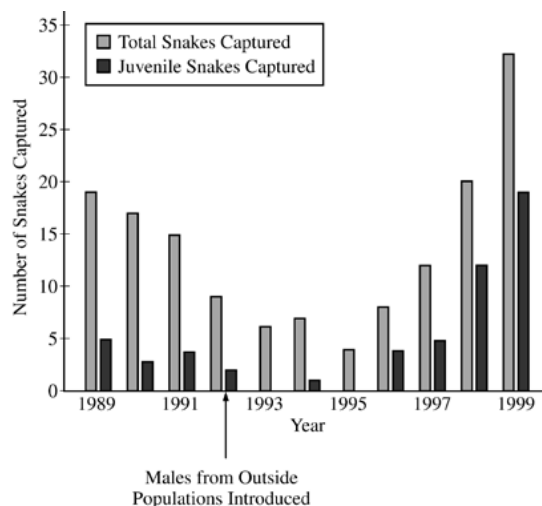
- Tip produces a substance/signal/hormone (auxin) in response to light causing the plants to bend
- Substance must diffuse from the tip causing the plants to bend

2015 SCORING GUIDELINES

Question 6

In an attempt to rescue a small isolated population of snakes from decline, a few male snakes from several larger populations of the same species were introduced into the population in 1992. The snakes reproduce sexually, and there are abundant resources in the environment.

The figure below shows the results of a study of the snake population, both before and after the introduction of the outside males. In the study, the numbers of captured snakes is an indication of the overall population size.



- (a) **Describe** ONE characteristic of the original population that may have led to the population's decline in size between 1989 and 1993.

Description (1 point)

- Lacked genetic diversity/variation
- Was an aged/post-reproductive population/not enough young snakes
- Had unfavorable sex ratio/too few males
- Possessed a harmful mutation/disease

- (b) **Propose** ONE reason that the introduction of the outside males rescued the snake population from decline.

Proposal (1 point)

- Increased genetic diversity in the population
- Increased reproductive success
- Established beneficial sex ratio/sufficient proportion of males for reproduction
- Introduced resistance to disease that was affecting the original population

- (c) **Describe** how the data support the statement that there are abundant resources in the environment.

Description (1 point)

- Population can/does grow
- If resources are limited population would not grow

2015 SCORING GUIDELINES

Question 7

Smell perception in mammals involves the interactions of airborne odorant molecules from the environment with receptor proteins on the olfactory neurons in the nasal cavity. The binding of odorant molecules to the receptor proteins triggers action potentials in the olfactory neurons and results in transmission of information to the brain. Mammalian genomes typically have approximately 1,000 functional odorant-receptor genes, each encoding a unique odorant receptor.

- (a) **Describe** how the signal is transmitted across the synapse from an olfactory sensory neuron to the interneuron that transmits the information to the brain.

Description (1 point)

- Neurotransmitters are released from the olfactory neuron and bind to receptors in the postsynaptic neuron.

- (b) **Explain** how the expression of a limited number of odorant receptor genes can lead to the perception of thousands of odors. Use the evidence about the number of odorant receptor genes to **support** your explanation.

Explanation and support (2 points maximum: points may be earned from only one row)

	Explanation (1 point)	Support (1 point)
Molecular	• One odorant molecule can be recognized by more than one odorant receptor • One odorant receptor can bind to more than one odorant molecule	Mathematical combinations expand possible odors detected
CNS Control	Signals integrated in the brain	Multiple interactions among neurons in the brain
Genetic	Alternate processing/splicing (of pre-mRNA/primary transcript)	Multiple receptors can be produced from a gene

2015 SCORING GUIDELINES**Question 8**

An individual has lost the ability to activate B-cells and mount a humoral immune response.

- (a) **Propose** ONE direct consequence of the loss of B-cell activity on the individual's humoral immune response to an initial exposure to a bacterial pathogen.

Proposal (1 point)

- Does not produce antibodies
- Does not produce memory B cells

- (b) **Propose** ONE direct consequence of the loss of B-cell activity on the speed of the individual's humoral immune response to a second exposure to the bacterial pathogen.

Proposal (1 point)

- Does not mount a faster response than the first response
- Mounts a second response at the same speed as the first response
- Mounts a second response more slowly than would a normal individual

- (c) **Describe** ONE characteristic of the individual's immune response to the bacterial pathogen that is not affected by the loss of B cells.

Description (1 point)

- Cell-mediated immunity still active
- Components of cell mediated immunity (e.g., Natural Killer/ Cytotoxic T cells) still active
- Nonspecific immune response remains active
- Components of non-specific immunity (e.g., macrophage/ phagocyte, epidermis) still active