Question 1: Interpreting and Evaluating Experimental Results — 9 points

Most proteins that are secreted from a cell must be transported to the endoplasmic reticulum (ER) either during translation or after translation.

For proteins transported during translation, this process begins in the cytosol and pauses when a specific sequence of amino acids is translated. The translation complex is then transported to the surface of the ER where translation continues. Proteins that are transported after translation are translated entirely in the cytosol and then transported to the ER. In both instances, the translated proteins enter the ER through a protein channel in the membrane of the ER.

Researchers studying the two types of protein transport identified that the ER membrane protein SR is necessary for transport during translation, while the ER membrane protein Sec62 is necessary for transport after translation. To investigate which transport mechanism is used for different proteins, researchers first created small interfering RNAs (siRNAs) that reduce expression of either SR or Sec 62. They then treated groups of cells with either the SR siRNA or the Sec62 siRNA and determined the relative amount of SR and Sec 62 protein in each group of cells compared with cells treated with a control siRNA. (Figure 1).

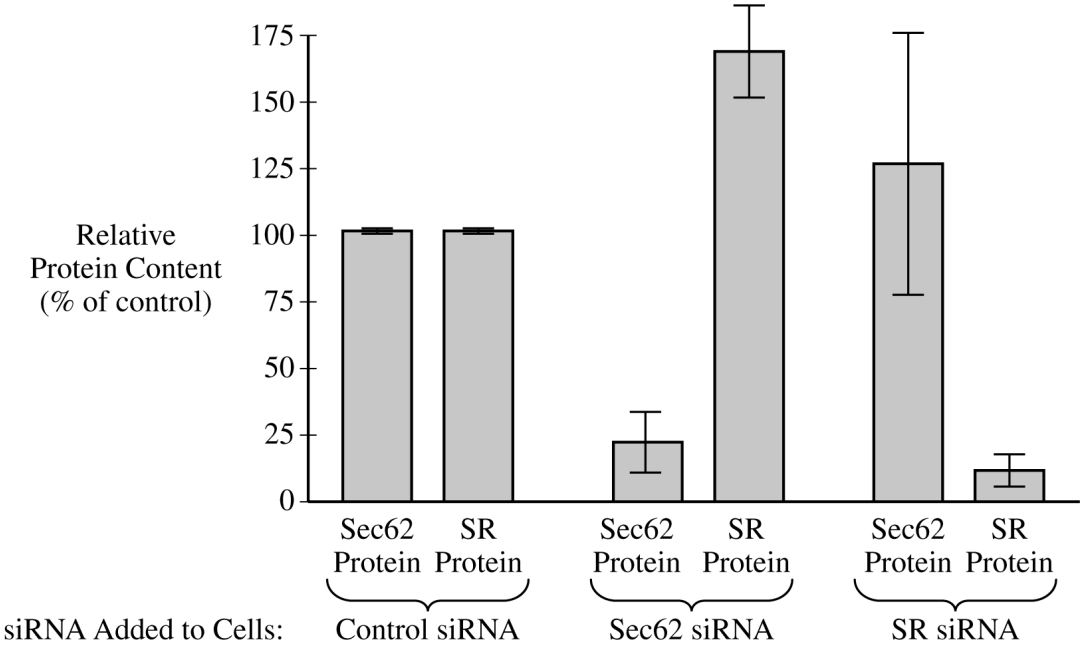


Figure 1. Average relative amounts of Sec62 and SR proteins in cells treated with control siRNA, Sec62 siRNA or SR siRNA. Error bars represent $\pm SE_{\bar{X}}$.

The researchers then measured the amount of each of three different proteins that was transported to the ER in cells treated with Sec62 siRNA or SR siRNA. The researchers calculated the percent transported relative to the cells treated with control siRNA (Figure 2).

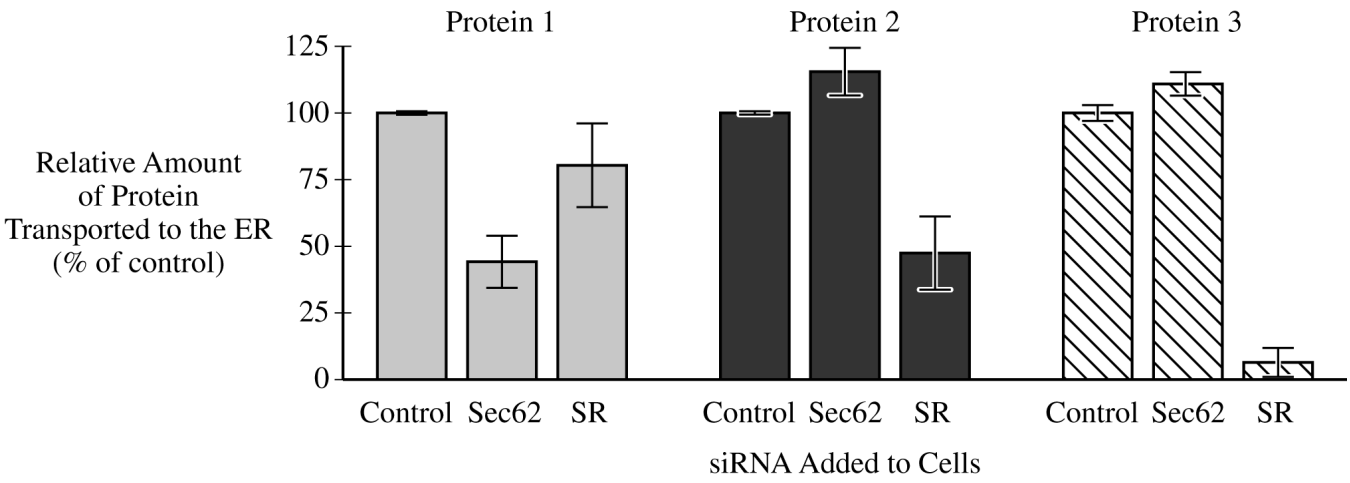


Figure 2. Average relative amounts of three proteins that were transported to the ER when treated with control siRNA, Sec62 siRNA, or SR siRNA. Error bars represent $\pm SE_{\bar{X}}$.

A	**Describe** the function of ribosomes. Examples of acceptable responses may include the following: • Ribosomes synthesize polypeptides/proteins. • Ribosomes perform translation. • Ribosomes are sites of polypeptide/protein synthesis.	**Point A1**
B	(i) **Identify** the dependent variable in the experiments shown in Figure 1. • The (relative) amount of protein/protein content	**Point B1**
	(ii) **Justify** why the researchers included the control of measuring the relative amounts of both Sec62 and SR proteins in cells that were treated with Sec62 siRNA only (data shown in Figure 1). Examples of acceptable responses may include the following: • (The control allowed the researchers) to determine whether the (Sec62) siRNA reduced/affected the content of both proteins (relative to protein content in the presence of the control siRNA). • (The control allowed the researchers) to determine whether the (Sec62) siRNA reduced/affected Sec62 (protein content) only.	**Point B2**
	(iii) Based on Figure 1, **describe** the effect on the production of SR protein when cells are treated with Sec62 siRNA. Examples of acceptable responses may include the following: • (SR protein production) increased. • (SR protein production) increased by 65% (accept 50–80%).	**Point B3**

C	(i) **Identify** the independent variable in the researchers' second experiment (data shown in Figure 2). Examples of acceptable responses may include the following: • (The type of) siRNA (added to the cells) • The type of protein whose amount was measured	**Point C1**
	(ii) Based on Figure 2, **identify** the protein(s) that when treated with Sec62 siRNA showed an increase in percent transport to the ER compared with the control. Examples of acceptable responses may include the following: • Proteins 2 and 3 • Protein 2 • Protein 3	**Point C2**
	(iii) Protein 1 is encoded by 234 nucleotides, while protein 2 is encoded by 495 nucleotides. Assuming all nucleotides for both proteins encode amino acids, **calculate** the difference in the number of amino acids between the two proteins. • 87 (amino acids) [(495/3)−(234/3)]	**Point C3**
D	(i) Researchers claim that protein 1 is the only tested protein that is transported to the ER following its complete translation in the cytosol. Using data from Figure 2, **support** the researchers' claim. • Only protein 1 showed a reduced amount/percentage of transport when cells were treated with Sec62 siRNA.	**Point D1**
	(ii) For any protein that enters the ER, researchers claim that amino acids close to the protein's amino terminus determine how likely the protein is to pass through the protein channel within the ER membrane. **Justify** the researchers' claim based on your understanding of factors that affect the transport of proteins across membranes. • Amino acids (at the amino terminus) that have similar polarity to/opposite charge to (the R groups of amino acids lining) the protein channel are more likely to pass through the channel (than are proteins where the amino terminus contains amino acids with dissimilar polarity or similar charge).	**Point D2**

Question 6: Analyze Data — 4 points

Scientists can quantify the rate of translation as ribosomes move along an mRNA from one codon to the next. Using a procedure called ribosome profiling, the scientists measured how long a ribosome remains stationary at each codon of each mRNA. They determined the average translation rate across all codons is 5.2 amino acids per second but that the average translation rate for specific codons in different mRNA sequences can vary widely. These variations in translation rates are thought to facilitate correct folding of the protein being produced. The rate at which three different codons were translated was measured in 100 different mRNAs. The scientists determined the distribution of rate (number of times each rate was recorded) for each of the three codons: GAC (Figure 1A), AUU (Figure 1B), and UGG (Figure 1C).

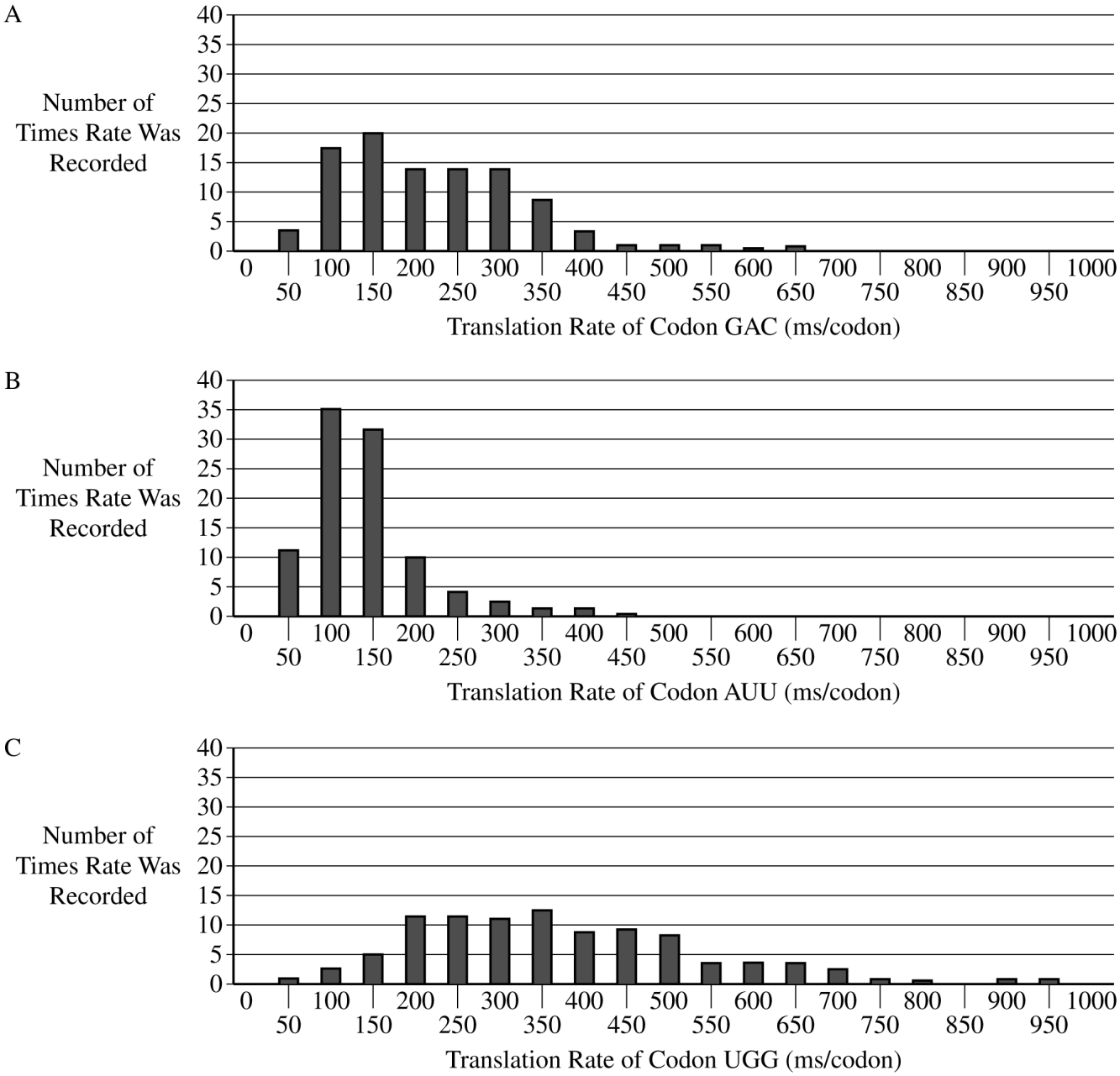


Figure 1. The distribution of translation rates for three different codons (A) GAC, (B) AUU, and (C) UGG

(a)	Using the data in Figure 1, graph A, **identify** the rate (in ms/codon) that was recorded the greatest number of times for the GAC codon. • 150	**1 point**
(b)	Using the data in Figure 1, graphs B and C, **describe** the variation in translation rate of the AUU codon compared with that of the UGG codon. Accept one of the following: • There is greater variation in (the translation rate of) UGG codons (than in the translation rate of AUU codons). • (The translation rate of) UGG ranges from 50 (ms/codon) to 950 (ms/codon), while (the translation rate of) AUU ranges from 50 (ms/codon) to 450 (ms/codon).	**1 point**
(c)	Scientists hypothesize that tRNA molecules that bind to UGG codons are available in lower abundance than are tRNAs that bind to AUU codons. **Support** the scientists' hypothesis using the data in Figure 1. Accept one of the following: • The (average) translation rate of UGG is slower (than that of AUU). • Translation of UGG takes longer (per codon than does translation of AUU). • More of the UGG codons were translated at slower rates (than AUU codons were).	**1 point**
(d)	Amino acids can be encoded by multiple codons. In many organisms, certain codons for the same amino acid occur more frequently in an mRNA than do other codons. Based on the data provided, **explain** why the use of one codon over another for the same amino acid might result in increased levels of protein production from a particular mRNA. • Certain codons are translated at faster rates than are others (and result in increased levels of protein production from a particular mRNA).	**1 point**
	Total for question 6	**4 points**

Question 1: Interpreting and Evaluating Experimental Results with Experimental Design — 9 points

In eukaryotic microorganisms, the PHO signaling pathway regulates the expression of certain genes. These genes, *Pho* target genes, encode proteins involved in regulating phosphate homeostasis. When the level of extracellular inorganic phosphate (Pi) is high, a transcriptional activator Pho4 is phosphorylated by a complex of two proteins, Pho80–Pho85. As a result, the *Pho* target genes are not expressed. When the level of extracellular Pi is low, the activity of the Pho80–Pho85 complex is inhibited by another protein, Pho81, enabling Pho4 to induce the expression of these target genes. A simplified model of this pathway is shown in Figure 1.

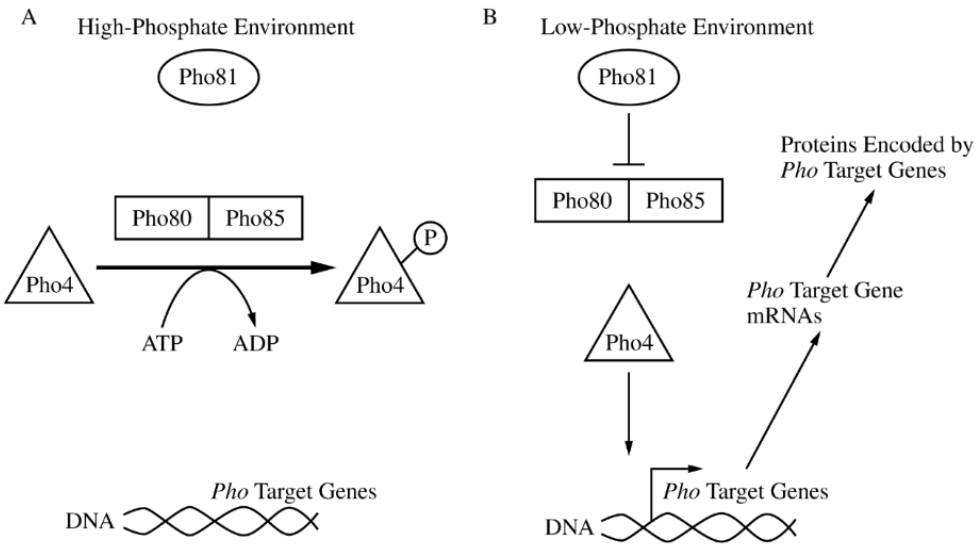


Figure 1. A simplified model of the regulation of expression of *Pho* target genes in (A) a high-phosphate (high-Pi) environment and (B) a low-phosphate (low-Pi) environment

To study the role of the different proteins in the PHO pathway, researchers used a wild-type strain of yeast to create a strain with a mutant form of Pho81 (*pho81mt*) and a strain with a mutated form of Pho4 (*pho4mt*). In each of these mutant strains, researchers measured the activity of a particular enzyme, APase, which removes phosphates from its substrates and is encoded by *PHO1*, a *Pho* target gene (Table 1). They then determined the level of *PHO1* mRNA relative to that of the wild-type yeast strain, which was set to 10.

TABLE 1. APase ACTIVITY AND RELATIVE AMOUNTS OF *PHO1* mRNA IN WILD-TYPE AND MUTANT STRAINS OF YEAST IN HIGH- AND LOW-PHOSPHATE ENVIRONMENTS

Yeast Strain	Mutation	APase Activity in High-Pi Environment (mU/mL/OD_{600}) $\pm 2SE_{\bar{x}}$	APase Activity in Low-Pi Environment (mU/mL/OD_{600}) $\pm 2SE_{\bar{x}}$	Relative Amounts of *PHO1* mRNA in High-Pi Environment $\pm 2SE_{\bar{x}}$	Relative Amounts of *PHO1* mRNA in Low-Pi Environment $\pm 2SE_{\bar{x}}$
Wild-type	None	0.5 ± 0.1	17.3 ± 0.9	0.1 ± 0.0	10 ± 2.0
pho81mt	Nonfunctional Pho81	0.4 ± 0.1	0.6 ± 0.1	0.7 ± 0.2	0.9 ± 0.8
pho4mt	Nonfunctional Pho4	0.5 ± 0.0	0.8 ± 0.2	0.6 ± 0.4	0.3 ± 0.1

(a) **Describe** the effect the addition of a charged phosphate group can have on a protein that would cause the protein to become inactive. **1 point**

- It changes the structure/shape of the protein.

Explain how a signal can be amplified during signal transduction in a pathway such as the PHO signaling pathway. **1 point**

- Each enzyme (in a signal transduction pathway) can act on many copies of a protein.

Total for part (a) **2 points**

(b) Based on Table 1, **identify** a dependent variable in the researchers' experiment. **1 point**

Accept one of the following:

- APase activity
- (Relative) amount of *PHO1* (mRNA)

Justify the researchers' using the wild-type strain for the creation of the mutant strains. **1 point**

Accept one of the following:

- It ensures that any observed differences (in experimental results) between the strains are due to the introduced mutations (and not to other genetic differences between the yeast strains).
- It ensures that the strains are genetically identical except for the introduced mutations.

Justify the researchers' using mutant strains in which only a single component of the pathway was mutated in each strain. **1 point**

Accept one of the following:

- It allows them to test the effect of each mutation separately.
- It allows them to (better) determine which component is responsible for any observed differences.

Total for part (b) **3 points**

(c)	Based on the data in Table 1, **identify** the yeast strain and growth conditions that lead to the highest relative amount of *PHO1* mRNA. • Wild-type yeast in a low-Pi environment	**1 point**
	Calculate the percent change in APase activity in wild-type yeast cells in a high-Pi environment compared with that of wild-type cells in a low-Pi environment. Accept one of the following: • 3,360% [(17.3–0.5)/0.5 × 100%] • -97% [(0.5–17.3)/17.3 × 100%]	**1 point**
	Total for part (c)	**2 points**
(d)	In a follow-up experiment, researchers created a strain of yeast with a mutation that resulted in a nonfunctional Pho85 protein. Based on Figure 1, **predict** the effects of this mutation on *PHO1* expression in the mutant strain in a high-Pi environment. • It/*PHO1*/Target genes will be expressed.	**1 point**
	Provide reasoning to **justify** your prediction. • (In a high-Pi environment) a nonfunctional Pho85 will be unable to phosphorylate/inhibit Pho4.	**1 point**
	Total for part (d)	**2 points**
	Total for question 1	**9 points**

Question 6: Analyze Data — 4 points

Researchers are studying the use of RNA vaccines to protect individuals against certain diseases. To develop the vaccines, particular cells are first removed from an individual. Then mRNAs coding for specific proteins from a pathogen are introduced into the cells. The altered cells are injected back into the individual, where the cells make the proteins encoded by the introduced mRNAs. The individual then produces an immune response to the proteins that will help to protect the individual from developing a disease if exposed to the pathogen in the future.

When introduced into cells, the mRNAs used for vaccines must be stable so that they are not degraded before the encoded proteins are produced. Researchers developed several modified caps that they hypothesized might make the introduced mRNAs more stable than mRNAs with the normal GTP cap. To test the effect of the modified caps, the researchers produced mRNAs that differed only in their cap structure (no cap, the normal cap, or modified caps I, II, or III). They introduced the same amount of each mRNA to different groups of cells and measured the amount of time required for half of the mRNAs to degrade (mRNA half-life) and the total amount of protein translated from the mRNAs (Table 1).

TABLE 1. EFFECT OF mRNA CAP STRUCTURE ON mRNA HALF-LIFE AND PROTEIN TRANSLATED FROM THE INTRODUCED mRNA

5′ Cap Structure	mRNA Half-Life $\pm 2\mathrm{SE}_{\bar{X}}$ (hours after introduction into cells)	Total Amount of Protein Translated from mRNA $\pm 2\mathrm{SE}_{\bar{X}}$ (relative to amount in normal cap)
No cap	1.41 ± 0.02	0.011 ± 0.000
Normal GTP cap	16.10 ± 1.83	1.000 ± 0.007
Modified cap I	15.50 ± 1.57	4.777 ± 0.042
Modified cap II	27.00 ± 2.85	13.094 ± 0.307
Modified cap III	18.09 ± 0.81	6.570 ± 0.075

(a) Based on the data, **identify** which cap structure is most likely to protect the end of the mRNAs from degradation. — **1 point**

- Modified cap II

(b) Based on the data for the mRNAs with modified caps, **describe** the relationship between the mRNA half-life and the total amount of protein produced. — **1 point**

Accept one of the following:

- A longer mRNA half-life is associated with more protein.
- There is a positive correlation/relationship.

(c) After examining the data on mRNA half-lives and the amount of protein produced, the researchers hypothesized that each mRNA molecule with modified cap I was translated more frequently than was each mRNA molecule with the normal GTP cap. **Evaluate** their hypothesis by comparing the data in Table 1. — **1 point**

- The data support their hypothesis because the half-lives of the two mRNAs are the same, but the amount of protein produced from the mRNA with modified cap I is more than (four times as much as) that produced from the mRNA with the normal

(d) Introduction of mRNAs into cells allows the cells to produce foreign proteins that they might not normally produce. **Explain** why the production of a foreign protein may be more likely from the introduction of mRNA than DNA into cells. **1 point**

Accept one of the following:

- Protein production from the DNA requires (transcription) factors to initiate transcription.
- Protein production from the mRNA does not depend on (correct posttranscriptional) processing of the pre-mRNA.
- The cells may be unable to transcribe the DNA (while mRNA can be directly translated).

Total for question 6 4 points

2019

AP CollegeBoard

2019 SCORING GUIDELINES

Question 1

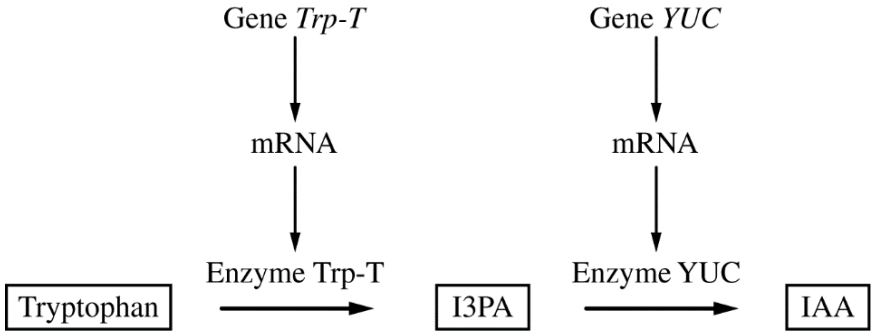


Figure 1. Model of two-step enzymatic plant pathway for synthesis of IAA from tryptophan

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

	Group I. Grown Separately		Group II. Grown Together	
Time (h)	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.

2019 SCORING GUIDELINES

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.

2019 SCORING GUIDELINES

Question 4

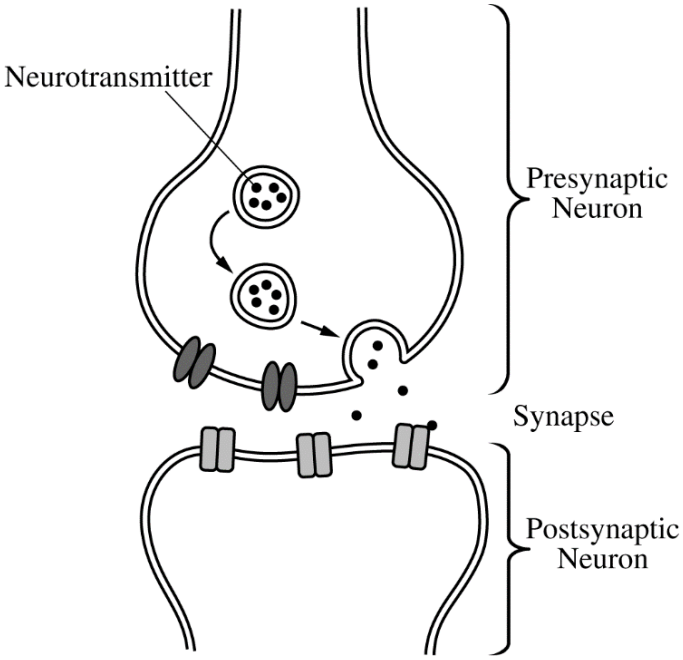


Figure 1. Release of neurotransmitters into the synapse in response to an action potential

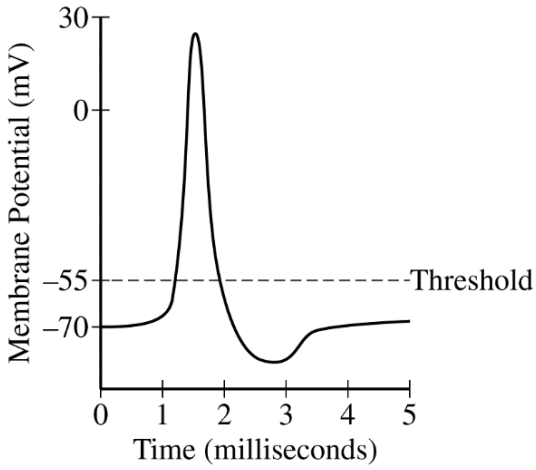


Figure 2. Model of a typical action potential in a neuron

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.

2019 SCORING GUIDELINES

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					-

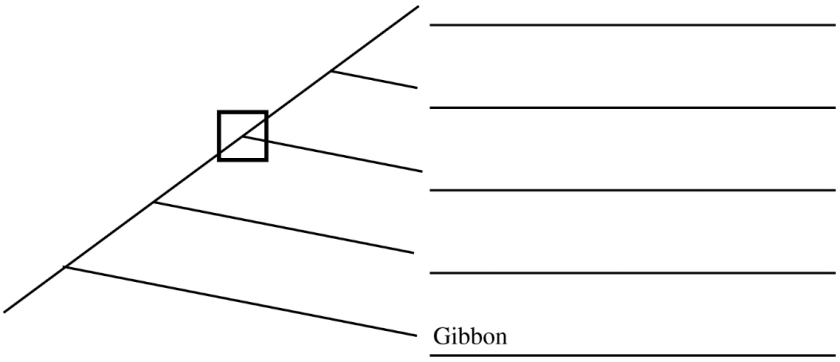
A researcher studying the evolutionary relationship among five primate species obtained data from a sequence of mitochondrial DNA (mtDNA) from a representative individual of each species. The researcher then calculated the percent divergence in the sequences between each pair of primate species (Table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

2019 SCORING GUIDELINES

Question 6

		STRAINS		
	MEDIUM	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.

2019 SCORING GUIDELINES

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.

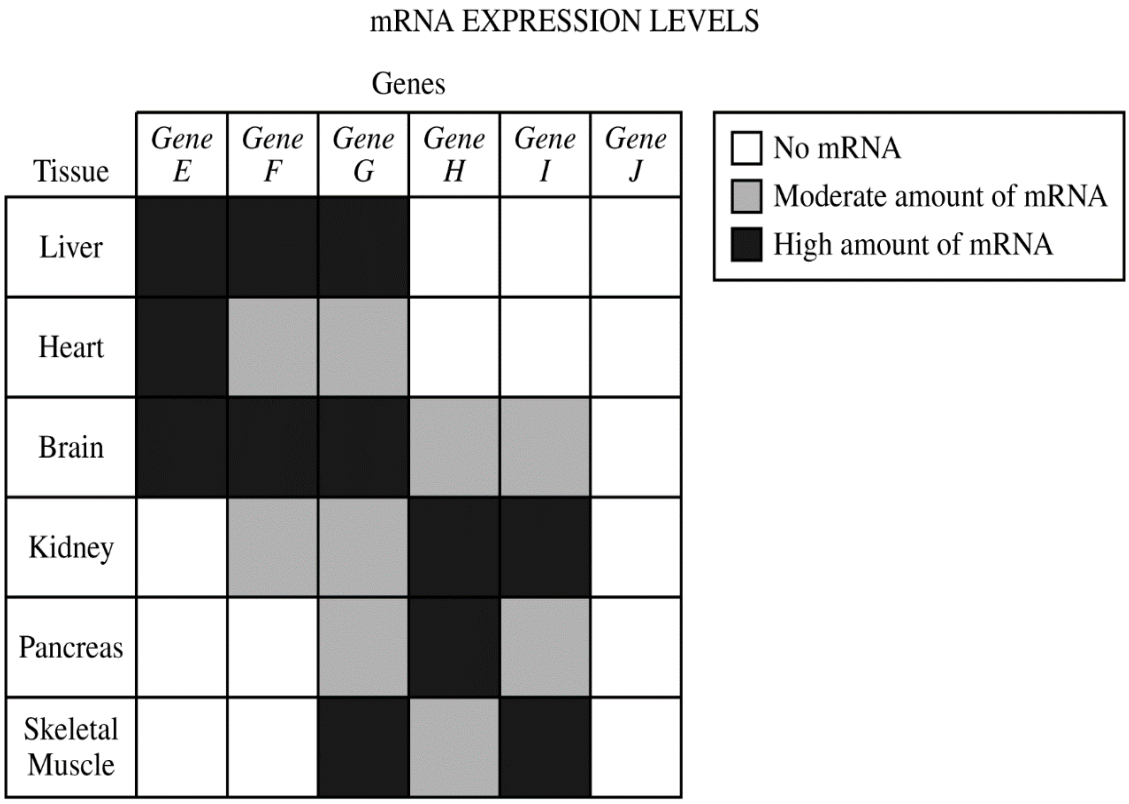


Figure 1. mRNA expression levels of six genes

(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.

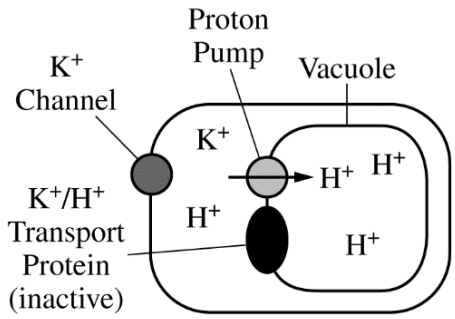
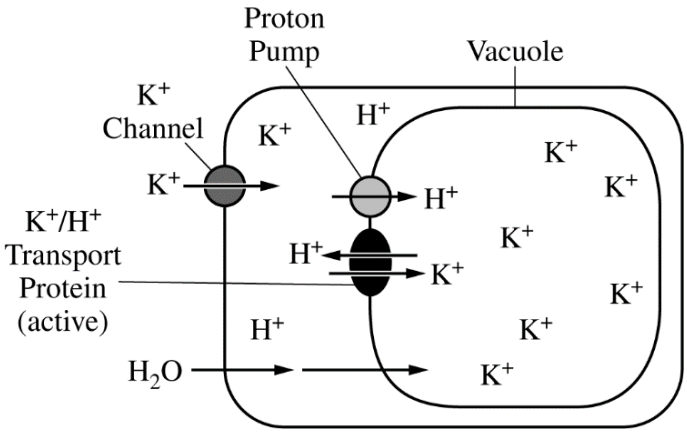
Reasoning (1 point)

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

2019 SCORING GUIDELINES

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.

2017

AP CollegeBoard

AP Biology

Scoring Guidelines

2017 SCORING GUIDELINES

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. **(4 points)**

2017 SCORING GUIDELINES

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.

2017 SCORING GUIDELINES

Question 2

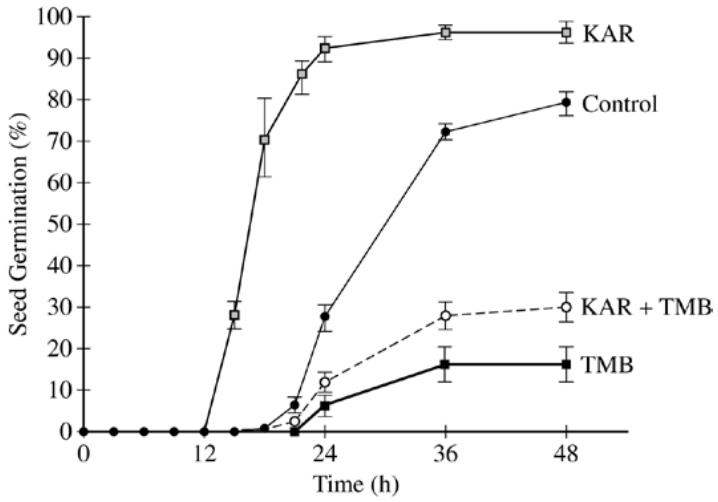


Figure 1. The effect of karrikins (KAR) and trimethylbutenolides (TMB) on seed germination in *Lactuca* plants. Error bars represent $\pm 2SE_{\bar{X}}$.

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

2017 SCORING GUIDELINES

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)**

<table>
<tr><th>Claim (2 points maximum; 1 point for KAR; 1 for TMB)</th><th colspan="5">Support (2 points maximum; 1 point for KAR; 1 for TMB)</th></tr>
<tr><td rowspan="2">• KAR remains (bound after rinsing)
• Rinsing does not affect KAR (binding)</td><td>KAR with no rinse</td><td>KAR with rinse</td><td rowspan="2">different than</td><td colspan="2">Controls</td></tr>
<tr><td>Group 2</td><td>Group 5</td><td>Group 1</td><td>Group 4</td></tr>
<tr><td rowspan="4">• TMB does not remain (bound)
• Rinsing affects TMB (binding)</td><td colspan="2">TMB with no rinse</td><td rowspan="2">different than</td><td colspan="2">Control</td></tr>
<tr><td colspan="2">Group 3</td><td colspan="2">Group 1</td></tr>
<tr><td colspan="2">TMB with rinse</td><td rowspan="2">same as</td><td colspan="2">Control</td></tr>
<tr><td colspan="2">Group 6</td><td colspan="2">Group 4</td></tr>
</table>

(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.

2017 SCORING GUIDELINES

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

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

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 ↔ A in the first position (of the codon)
- 5′-GCN-3′ ↔ 5′-ACN-3′
- 5′-NGC-3′ ↔ 5′-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.

2017 SCORING GUIDELINES

Question 4

DIETARY COMPOSITION OF ORGANISMS IN AN AQUATIC ECOSYSTEM

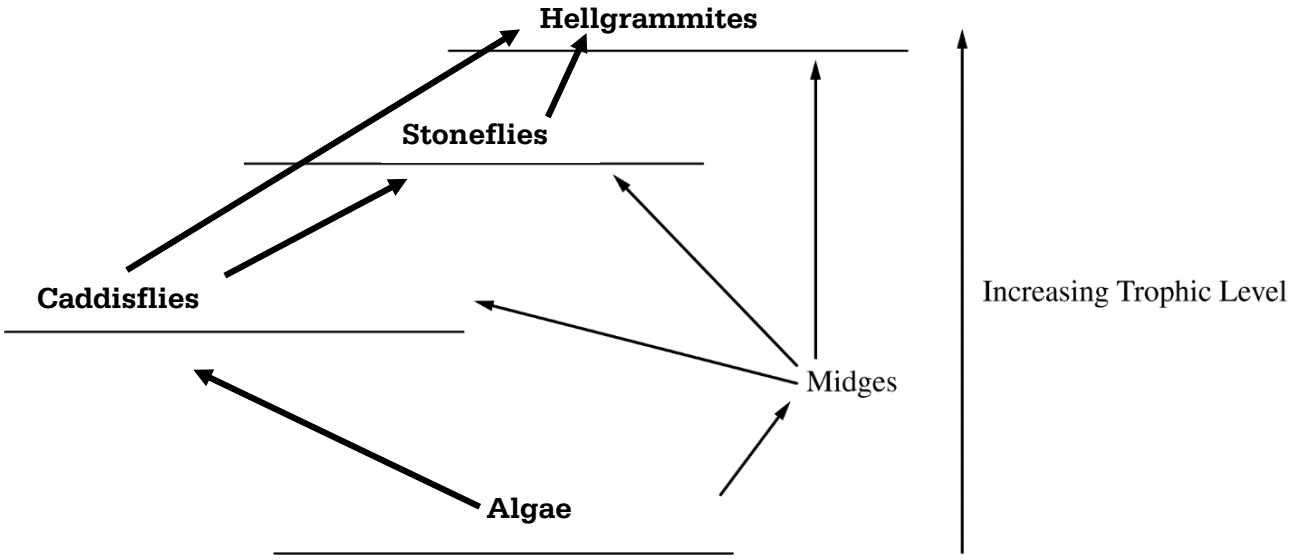
Organism	Food Source (% of diet)				
	Algae	Stoneflies	Midges	Hellgrammites	Caddisflies
Algae					
Stoneflies			90		10
Midges	100				
Hellgrammites		20	10		70
Caddisflies	70		30		

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



2017 SCORING GUIDELINES

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.

AP Biology: **2017**

2017 SCORING GUIDELINES

Question 5

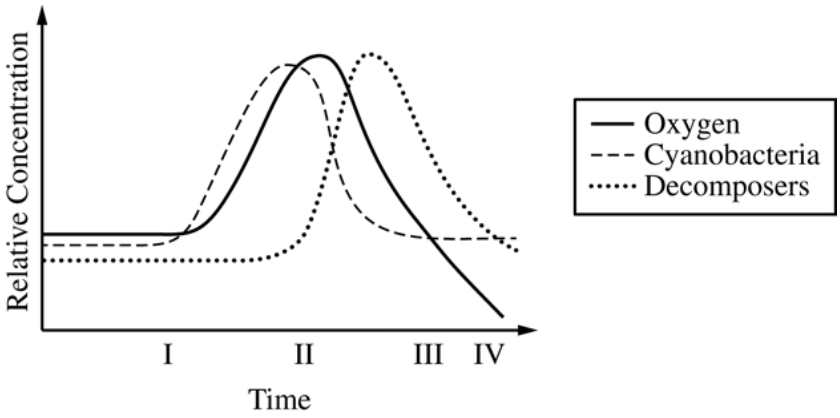


Figure 1. Characteristics of a pond community over time

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 (*M. aeruginosis*)
III – IV	Cellular respiration	Decomposers/fungi/bacteria

2017 SCORING GUIDELINES

Question 6

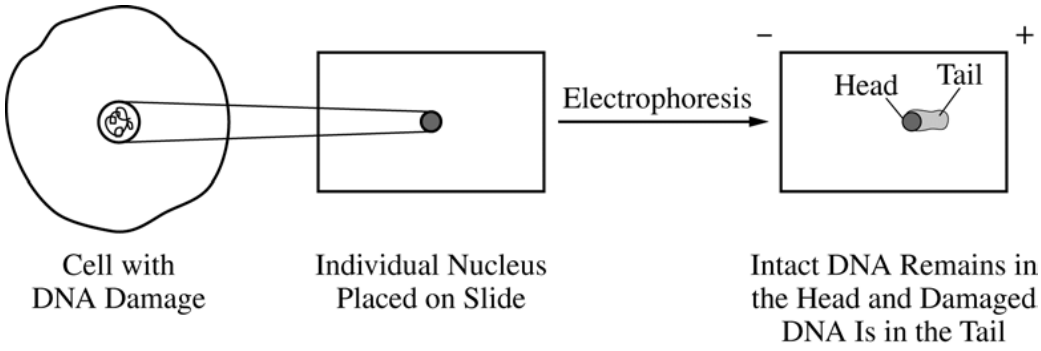


Figure 1. Comet assay to detect double-stranded breaks in DNA

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

2017 SCORING GUIDELINES

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.