

Question 2: Interpreting and Evaluating Experimental Results with Graphing

9 points

Many insects rely on pheromones (chemical signals) that are released by the females to find mating partners. Scientists hypothesize that, in a certain type of moth, the behavior of male moths in response to pheromones is regulated by the extracellular signaling molecule 20E.

To investigate whether the binding of 20E to its receptor, DopEcR, affects behavior in moths, scientists injected male moths with saline (control solution) or with small interfering RNA molecules (siRNAs) that inhibit the expression of the gene encoding DopEcR. The scientists then exposed the moths to the pheromone and determined the percent of total time observed that the moths engaged in general activity, defined as movement in any direction. The scientists also determined the percent of the general activity time that the moths spent in oriented activity, defined as movement toward an area of high pheromone concentration (Table 1).

Table 1. Average General and Oriented Activity in Male Moths Injected With Saline or siRNA Molecules

Treatment	General Activity (percent of total time observed, average $\pm 2SE_{\bar{x}}$)	Oriented Activity (percent of general activity, average $\pm 2SE_{\bar{x}}$)
Male moths injected with saline (control solution)	95 ± 5	60 ± 4
Male moths injected with siRNAs that inhibit expression of the gene encoding DopEcR	90 ± 8	25 ± 6

DopEcR is a G protein-coupled receptor. When 20E binds to DopEcR, GTP displaces the GDP bound to the G protein, and a signaling pathway is activated. The scientists hypothesize that this leads to the transcription of genes associated with the oriented activity observed in the male moths (Figure 1).

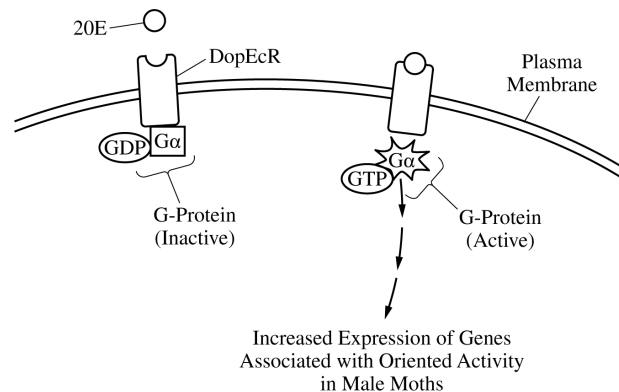


Figure 1. A simplified model of a signaling pathway activated by the binding of 20E to its receptor, DopEcR

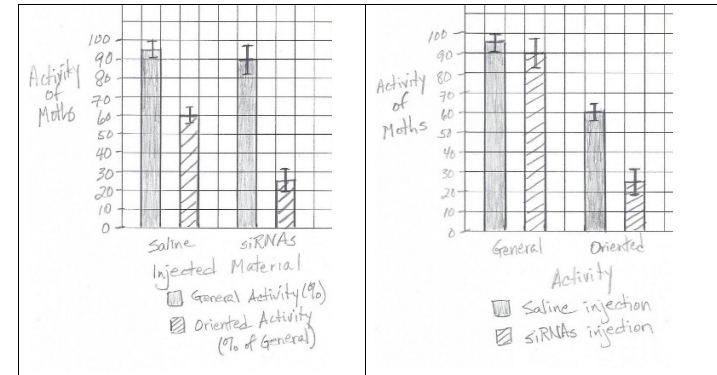
A Many receptors are embedded in the plasma membrane. **Describe** the polarity of the portion of the receptor that is inside the membrane. **Point A1**

Examples of acceptable responses may include the following:

- (The portion of the receptor inside the membrane) is nonpolar.
- (The portion of the receptor inside the membrane) is hydrophobic.

B (i) Using the template in the space provided for your response, **construct** an appropriate type of graph that represents the data in Table 1. Your graph should be appropriately plotted and labeled. **Point B1**

- Data are represented in a bar/modified bar graph.
- Examples of acceptable responses may include the following:



(i) Using the template in the space provided for your response, **construct** an appropriate type of graph that represents the data in Table 1. Your graph should be appropriately plotted and labeled. **Point B2**

- Data and error bars are accurately plotted.

(i) Using the template in the space provided for your response, **construct** an appropriate type of graph that represents the data in Table 1. Your graph should be appropriately plotted and labeled. **Point B3**

- Graph is appropriately labeled.

(ii) Based on the data in Table 1, **determine** the type of activity that was affected by inhibiting the expression of the DopEcR receptor. **Point B4**

- Oriented activity (was affected).

- C** (i) Based on Table 1, identify the treatment group in which the oriented activity was greater than 50% of the general activity. **Point C1**
 Examples of acceptable responses may include the following:
- The control/saline-treated group
 - Male moths injected with saline/control solution
- (ii) The scientists studied some moths with a mutation in the gene encoding the G protein. **Point C2**
 The mutation prevents GTP from displacing the GDP bound to the G protein. Based on Figure 1, **predict** the effect of this mutation on the oriented activity in male moths exposed to the pheromone.
- (The moths will show) decreased (oriented) activity.
- D** (i) Expression of the gene encoding DopEcR is low in the male moths during their first few days as adults, when they are sexually immature. Gene expression rapidly increases as the moths reach sexual maturity. The scientists claim that this increase in gene expression increases the likelihood of males finding females with whom to mate. Use evidence from the information provided to **support** the scientists' claim. **Point D1**
 Examples of acceptable responses may include the following:
- (Increased expression of DopEcR) will increase oriented activity (and the moths' ability to find a mate).
 - (An increase in DopEcR expression) will enable the binding of 20E to more receptors.
 - (An increase in DopEcR expression) will make the males more sensitive to pheromones from the females.
 - (An increase in DopEcR expression) will enable the binding of 20E to more receptors and will make the males more sensitive to pheromones from the females.
- (ii) Based on Figure 1, **explain** how an inhibitor of the DopEcR pathway might serve as an effective chemical to protect crops from moth damage. **Point D2**
- (An inhibitor of the pathway) will reduce oriented activity/expression of genes associated with oriented activity and therefore decrease mating/population growth.

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.

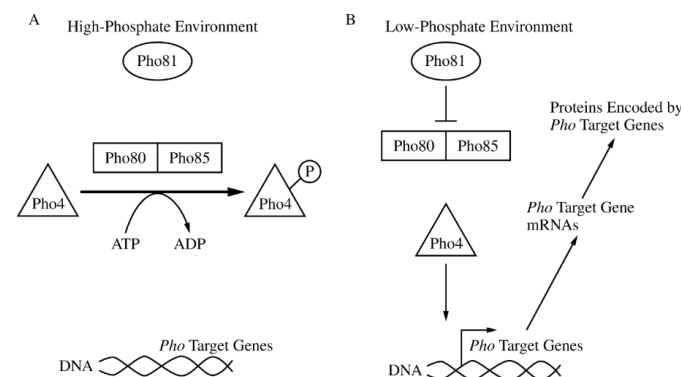


Figure 1. A simplified model of the regulation of expression of *Pho* target genes in (A) a high-phosphate (high-Pi) environment and (B) a low-phosphate (low-Pi) environment

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 <i>PHO1</i> mRNA in High- Pi Environment $\pm 2SE_{\bar{x}}$	Relative Amounts of <i>PHO1</i> mRNA in Low- Pi Environment $\pm 2SE_{\bar{x}}$
Wild-type	None	0.5 $\pm$ 0.1	17.3 $\pm$ 0.9	0.1 $\pm$ 0.0	10 $\pm$ 2.0
<i>pho81mt</i>	Nonfunctional Pho81	0.4 $\pm$ 0.1	0.6 $\pm$ 0.1	0.7 $\pm$ 0.2	0.9 $\pm$ 0.8
<i>pho4mt</i>	Nonfunctional Pho4	0.5 $\pm$ 0.0	0.8 $\pm$ 0.2	0.6 $\pm$ 0.4	0.3 $\pm$ 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. **1 point**
- Wild-type yeast in a low-Pi environment
- 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. **1 point**
- Accept one of the following:
- 3,360% $[(17.3-0.5)/0.5 \times 100\%]$
 - 97% $[(0.5-17.3)/17.3 \times 100\%]$
- 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. **1 point**
- It/PHO1/Target genes will be expressed.
- Provide reasoning to justify your prediction. **1 point**
- (In a high-Pi environment) a nonfunctional Pho85 will be unable to phosphorylate/inhibit Pho4.
- Total for part (d) 2 points**
- Total for question 1 9 points**

Question 1: Interpreting and Evaluating Experimental Results with Experimental Design

9 points

The binding of an extracellular ligand to a G protein-coupled receptor in the plasma membrane of a cell triggers intracellular signaling (Figure 1, A). After ligand binding, GTP replaces the GDP that is bound to $G\alpha$, a subunit of the G protein (Figure 1, B). This causes $G\alpha$ to activate other cellular proteins, including adenylyl cyclase that converts ATP to cyclic AMP (cAMP). The cAMP activates protein kinases (Figure 1, C). In cells that line the small intestine, a cAMP-activated protein kinase causes further signaling that ultimately results in the secretion of chloride ions (Cl^-) from the cells. Under normal conditions, $G\alpha$ hydrolyzes GTP to GDP, thus inactivating adenylyl cyclase and stopping the signal (Figure 1, A).

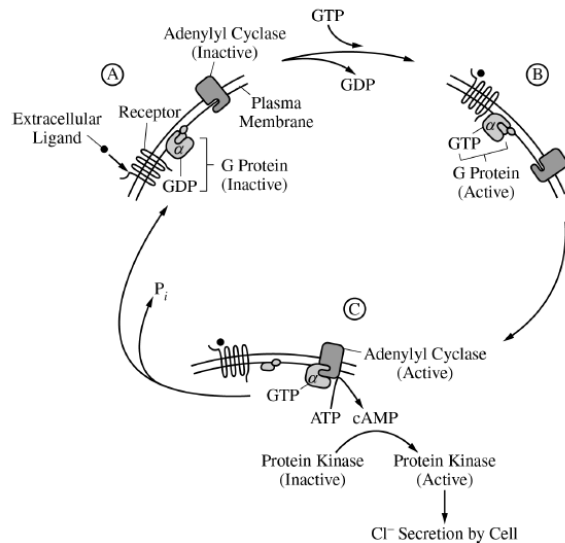


Figure 1. Under normal conditions, ligand binding to a G protein-coupled receptor results in chloride ion transport from an intestinal cell.

Individuals infected with the bacterium *Vibrio cholerae* experience severe loss of water from the body (dehydration). This is due to the effects of the bacterial cholera toxin that enters intestinal cells. Scientists studied the effects of cholera toxin on four samples of isolated intestinal cell membranes containing the G protein-related signal transduction components shown in Figure 1. GTP was added to samples II and IV only; cholera toxin was added to samples III and IV only. The scientists then measured the amount of cAMP produced by the adenylyl cyclase in each sample (Table 1).

TABLE 1. AMOUNT OF cAMP PRODUCED FROM INTESTINAL CELL MEMBRANES IN THE ABSENCE OR PRESENCE OF CHOLERA TOXIN

Sample	GTP	Cholera Toxin	Rate of cAMP Production (pmol per mg adenylyl cyclase per min)
I	—	—	0.5
II	+	—	10.0
III	—	+	0.5
IV	+	+	127.0

present, +; absent, —

- (a) Describe one characteristic of a membrane that requires a channel be present for chloride ions to passively cross the membrane. **1 point**

Accept one of the following:

- The interior of the membrane/phospholipid tail is nonpolar.
- The interior of the membrane/phospholipid tail is not charged.
- The interior of the membrane/phospholipid tail is hydrophobic.

Explain why the movement of chloride ions out of intestinal cells leads to water loss. **1 point**

Accept one of the following:

- The space outside of the cells becomes hypertonic/hyperosmotic compared with the cells, so water moves out of the cells.
- The space outside of the cells would have a lower water potential compared with the cells, so water will move out of the cells.

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

- (b) Identify an independent variable in the experiment. **1 point**

Accept one of the following:

- The presence or absence of cholera toxin
- The presence or absence of GTP

Identify a negative control in the experiment. **1 point**

Accept one of the following:

- The sample lacking both cholera toxin and GTP /sample I
- The samples that lack cholera toxin /samples I and II
- The sample that lacks cholera toxin but contains GTP /sample II
- The samples that lack GTP /samples I and III

Justify why the scientists included Sample III as a control treatment in the experiment. **1 point**

Accept one of the following:

- (Sample III serves as a control) to compare cAMP production with that of the sample having cholera toxin and GTP /sample IV.
- Comparing sample III and sample IV enables the scientists to evaluate whether the activity of cholera toxin requires GTP/acts via the G protein pathway.

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

(c) Based on the data, describe the effect of cholera toxin on the synthesis of cAMP. 1 point Accept one of the following: - Cholera toxin increases the production of cAMP in the presence of GTP (IV vs II). - Cholera toxin has no effect on the production of cAMP in the absence of GTP (III vs I). Calculate the percent change in the rate of cAMP production due to the presence of cholera toxin in sample IV compared with sample II. 1 point 1,170% $[(127-10)/10 = 11.7 \times 100]$ Total for part (c) 2 points	
(d) A drug is designed to bind to cholera toxin and prevent the toxin from crossing the intestinal cell membrane. Scientists mix the drug with cholera toxin and then add this mixture and GTP to a sample of intestinal cell membranes. Predict the rate of cAMP production in pmol per mg adenylyl cyclase per min if the drug binds to all of the toxin. 1 point - The rate will be 10 (pmol per mg adenylyl cyclase per min). In a separate experiment, scientists engineer a mutant adenylyl cyclase that cannot be activated by $G_{s\alpha}$. The scientists claim that cholera toxin will not cause excessive water loss from whole intestinal cells that contain the mutant adenylyl cyclase. Justify this claim. 1 point (Even in the presence of the toxin) cAMP will not be produced (by this pathway), the protein kinases will not be activated, and Cl^- ions will not be secreted (and less water will leave the intestinal cells). Total for part (d) 2 points	
Total for question 1 9 points	

Question 1: Interpreting and Evaluating Experimental Results**10 points**

Polycystic kidney disease (PKD) is an inherited disease that causes water loss from the body and affects cell division in the kidneys. Because water movement across cell membranes is related to ion movement, scientists investigated the role of the Na^+/K^+ ATPase (also known as the sodium/potassium pump) in this disease.

Ouabain, a steroid hormone, binds to the Na^+/K^+ ATPase in plasma membranes. Individuals with PKD have a genetic mutation that results in an increased binding of ouabain to the Na^+/K^+ ATPase. The scientists treated normal human kidney (NHK) cells and PKD cells with increasing concentrations of ouabain and measured the number of cells (Figure 1) and the activity of the Na^+/K^+ ATPase (Figure 2) after a period of time. The scientists hypothesized that a signal transduction pathway that includes the protein kinases MEK and ERK (Figure 3) may play a role in PKD symptoms.

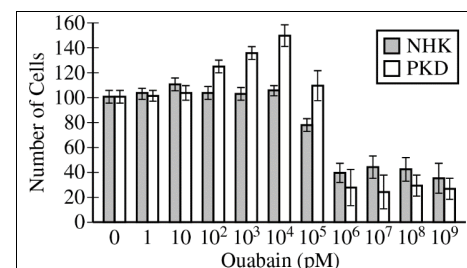


Figure 1. Cell number compared with the number of cells at 0 pM ouabain. Normal human kidney (NHK) cells and polycystic kidney disease (PKD) cells were treated with increasing concentrations of ouabain. Error bars represent $\pm 2SE_{\bar{x}}$.

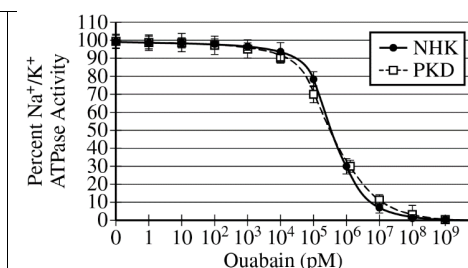


Figure 2. Percent Na^+/K^+ ATPase activity of NHK and PKD cells treated with increasing concentrations of ouabain. Error bars represent $\pm 2SE_{\bar{x}}$.

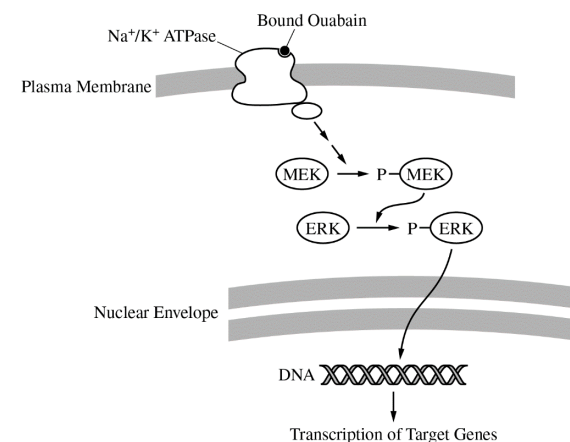


Figure 3. Signal transduction pathway hypothesized to play a role in the increased number of PKD cells

(a) Describe the characteristics of the plasma membrane that prevent simple diffusion of Na^+ and K^+ across the membrane. 1 point Accept one of the following: - The interior of the plasma membrane is hydrophobic/nonpolar. - The phospholipid tails are hydrophobic/nonpolar. - The exterior of the plasma membrane is hydrophilic/polar. - The phospholipid heads are hydrophilic/polar.	
Explain why ATP is required for the activity of the Na^+/K^+ ATPase. 1 point The Na^+/K^+ ATPase pumps ions against their concentration gradients. This requires an input of (metabolic) energy.	
Total for part (a) 2 points	
(b) Identify a dependent variable in the experiment represented in Figure 1. 1 point The number of cells	
Justify the use of normal human kidney NHK cells as a control in the experiments. 1 point Accept one of the following: - It allows the scientists to determine the effect of PKD on the cells' responses to (various concentrations of) ouabain. - It allows the scientists to compare the responses of PKD cells and normal cells (to ouabain).	
Justify the use of a range of ouabain concentrations in the experiment represented in Figure 1. 1 point Accept one of the following: - The scientists need to determine whether different concentrations have different effects on the cell numbers. - The scientists did not know at which concentration of ouabain there would be an effect.	
Total for part (b) 3 points	
(c) Based on the data shown in Figure 2, describe the relationship between the concentration of ouabain and the Na^+/K^+ ATPase activity both in normal human kidney (NHK) cells AND in PKD cells. 1 point Accept one of the following: - Increasing concentrations of ouabain result in decreasing ATPase activity (in both types of cells). - There is an inverse relationship/negative correlation between the concentration of ouabain and the ATPase activity (in both types of cells). The scientists determined that Na^+/K^+ ATPase activity in PKD cells treated with 1 pM ouabain is 150 units of ATP hydrolyzed/sec. Calculate the expected Na^+/K^+ ATPase activity (units/sec) in PKD cells treated with 10^6 pM ouabain. 1 point 45 (Accept between 40 and 50)	
Total for part (c) 2 points	

(d) In a third experiment, the scientists added an inhibitor of phosphorylated MEK (pMEK) to the PKD cells exposed to 10^4 pM ouabain. Based on Figure 3, predict the change in the relative ratio of ERK to pERK in ouabain-treated PKD cells with the inhibitor compared with ouabain-treated PKD cells without the inhibitor. 1 point Accept one of the following: - Option 1: The ratio of ERK to pERK will increase in the cells with the inhibitor. - Option 2: The ratio of ERK to pERK will stay the same in the cells with the inhibitor.	
Provide reasoning to justify your prediction. 1 point - The justification must indicate that the pMEK inhibitor blocks further phosphorylation of ERK <u>AND</u> one of the following: Option 1: - The amount of pERK will not increase as it does in cells without the inhibitor. - The amount of ERK will not decrease as it does in cells without the inhibitor. - The cell continues to synthesize ERK. - Phosphorylated ERK is being dephosphorylated to ERK. Option 2: - No additional ERK is synthesized/pERK is not being dephosphorylated.	
Using the data in Figure 1 <u>AND</u> the signal transduction pathway represented in Figure 3, explain why the concentration of cyclin proteins may increase in PKD cells treated with 10^4 pM ouabain. 1 point The cell number increases to a maximum at 10^4 pM ouabain. The signaling pathway stimulates transcription of genes involved in cell division. The target genes likely include those for cyclins because cyclins regulate the cell cycle.	
Total for part (d) 3 points	
Total for question 1 10 points	

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Scoring Guidelines

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Question 1

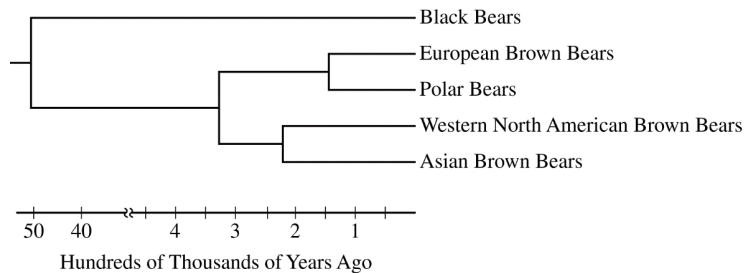


Figure 1. Phylogenetic tree representing the evolutionary relatedness among bear populations based on mitochondrial DNA sequence comparisons

Polar bears are highly adapted for life in cold climates around the North Pole. Brown bears, black bears, and pandas are found in warmer environments. Researchers collected complete mitochondrial DNA sequences from several populations of bears and constructed a phylogenetic tree to represent their evolutionary relatedness (Figure 1).

A researcher studying adaptation in bears sequenced the nuclear gene encoding a lysosomal trafficking protein (LYST) in polar bears, brown bears, black bears, and panda bears. There are seven inferred amino acid substitutions that are found only in polar bears. Mutations that cause similar substitutions in the human LYST protein are associated with Chediak-Higashi syndrome, an autosomal recessive condition in which pigment is absent from the hair and eyes. The researcher used the inferred amino acid sequences to build the distance matrix shown in Table 1.

TABLE 1. AMINO ACID DIFFERENCES IN THE LYST PROTEIN AMONG BEAR SPECIES

	Panda	Black	Brown	Polar
Panda	–			
Black	33	–		
Brown	34	1	–	
Polar	40	7	8	–

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Question 1 (continued)

- (a) Use the phylogenetic tree in Figure 1 to **estimate** the age in hundreds of thousands of years of the most recent common ancestor of all brown bears. **Identify** the population of brown bears to which polar bears are most closely related based on the mitochondrial DNA sequence comparison. **Identify** two populations whose positions could be switched without affecting the relationships illustrated in the phylogenetic tree.

Estimate (1 point)

- First two digits of the answer must be between 30 and 35.

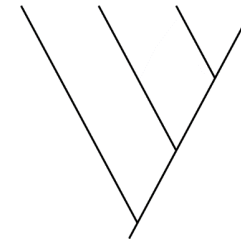
Identification (1 point)

- European

Identification (1 point)

- European/Polar OR Asian/Western (North American)

- (b) **Construct** a cladogram on the template to represent a model of the evolutionary relatedness among the bear species based on the differences in LYST protein sequences (Table 1). **Circle** the position on the cladogram that represents the out-group.

**Construction (1 point)**

- Correctly illustrated evolutionary relationship among the four species

Circling (1 point)

- Correctly circled out-group based on orientation of cladogram

- (c) A student claims that mitochondrial DNA sequence comparisons provide a more accurate phylogeny of bear species than do LYST protein sequence comparisons. **Provide ONE piece of reasoning** to support the student's claim.

Reasoning (1 point)

- Genes show more variability (in nucleotide sequence) than proteins do (in amino acid sequences).
- mtDNA genome contains multiple genes vs. one *lyst* gene.
- The phenotype associated with the *lyst* gene is under strong selection.

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Question 1 (continued)

- (d) A researcher genetically engineers a mouse strain by deleting the mouse *lyst* gene and replacing it with the polar bear *lyst* gene. **Predict** the most likely difference in phenotype of the transgenic mouse strain compared to the wild-type mouse strain. **Justify** your prediction.

Prediction (1 point)

- Mouse fur and/or eyes will not have pigment/will have reduced pigment.
- Mouse (fur) will be white/lighter.

Justification (1 point)

- Polar bear *lyst* gene/LYST protein is associated with a lack of pigment/white hair.
- Mutated human *lyst* gene/ LYST protein is associated with a lack of pigment in hair and eyes.

- (e) **Describe** how the mutation in the *lyst* gene became common in the polar bear population. If the *lyst* gene were the only determinant of fur color, **predict** the percent of white offspring produced by a mating between a polar bear and a brown bear.

Description (1 point)

- Natural selection for the white fur phenotype

Prediction (1 point)

- 0%

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Question 2

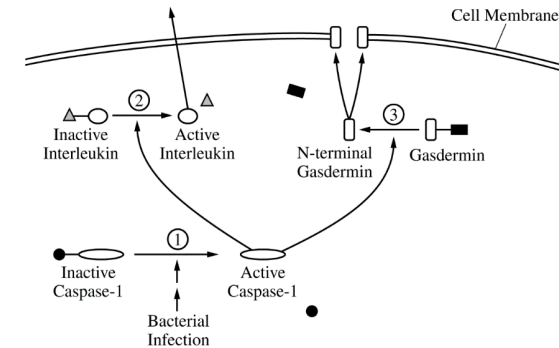


Figure 1. Cellular response to infection by pathogenic bacteria

Some pathogenic bacteria enter cells, replicate, and spread to other cells, causing illness in the host organism. Host cells respond to these infections in a number of ways, one of which involves activating particular enzymatic pathways (Figure 1). Cells normally produce a steady supply of inactive caspase-1 protein. In response to intracellular pathogens, the inactive caspase-1 is cleaved and forms an active caspase-1 (step 1). Active caspase-1 can cleave two other proteins. When caspase-1 cleaves an inactive interleukin (step 2), the active portion of the interleukin is released from the cell. An interleukin is a signaling molecule that can activate the immune response. When caspase-1 cleaves gasdermin (step 3), the N-terminal portions of several gasdermin proteins associate in the cell membrane to form large, nonspecific pores.

Researchers created the model in Figure 1 using data from cell fractionation studies. In the experiments, various parts of the cell were separated into fractions by mechanical and chemical methods. Specific proteins known to be located in different parts of the cell were used as markers to determine the location of other proteins. The table below shows the presence of known proteins in specific cellular fractions.

CELL FRACTIONS CONTAINING DIFFERENT CELLULAR PROTEINS

	Aconitase (Krebs cycle protein)	DNA polymerase	GAPDH (glycolytic protein)	Sodium- potassium pump	NF- κ B (Immune response protein)
Whole cell sample	+	+	+	+	+
Fraction 1	+				
Fraction 2		+			+
Fraction 3			+		+
Fraction 4				+	

+ = presence of protein

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Question 2 (continued)

(a) **Describe** the effect of inhibiting step 3 on the formation of pores AND on the release of interleukin from the cell.

Description (2 points)

- Pores will not form.
- Interleukin release will not be affected/interleukin release continues.

(b) **Make a claim** about how cleaving inactive caspase-1 results in activation of caspase-1. A student claims that preinfection production of inactive precursors shortens the response time of a cell to a bacterial infection. **Provide ONE reason** to support the student's claim.

Claim (1 point)

- Removes inhibitor/repressor/inhibitory domain of protein
- Changes the shape/protein structure

Reasoning (1 point)

- Cleaving a precursor/protein/molecule is faster than making one upon infection.
- Cells do not have to wait for transcription and translation/protein synthesis.

(c) A student claims that the NF- κ B protein is located in the cytoplasm until the protein is needed for transcription. **Justify** the student's claim with evidence. **Identify TWO** fractions where N-terminal gasdermin would be found in cells infected with pathogenic bacteria.

Justification (1 point)

- NF- κ B and glycolytic enzymes/GAPDH are found together (in the cytoplasm).

Identification (2 points)

- Fraction 3
- Fraction 4

(d) **Describe** the most likely effect of gasdermin pore formation on water balance in the cell in a hypotonic environment.

Description (1 point)

- Water enters the cell.

(e) **Explain** how gasdermin pore formation AND interleukin release contribute to an organism's defense against a bacterial pathogen.

Explanation (2 points)

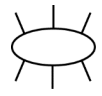
- Cell lysis destroys infected cells OR cell lysis prevents bacteria from replicating.
- Interleukin signaling will stimulate immune cells/components of the immune system (to destroy the infected cells or bacteria).

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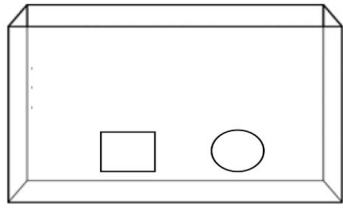
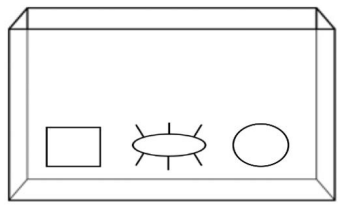
Question 3

Seagrasses are aquatic plants that reproduce sexually. Male seagrass flowers produce sticky pollen that is carried by circulating water to female flowers, resulting in fertilization. A researcher claims that mobile aquatic invertebrates can also transfer pollen from male to female flowers in the absence of circulating water. To investigate this claim, the researcher set up aquariums to model the possible interactions between the invertebrates and seagrasses.

(a) Use the symbols below and the template aquariums to demonstrate the experimental design for testing the researcher's claim that mobile aquatic invertebrates can pollinate seagrass in the absence of circulating water. **Draw** the appropriate symbols in the negative control aquarium AND the experimental aquarium. Do not use any symbol more than once in the same aquarium.

Male Flower	Female Flower	Invertebrates
		

Drawing (2 points)

Negative Control Aquarium (1 point)	Experimental Aquarium (1 point)
	

(b) **Identify** the dependent variable in the experiment. **Predict** the experimental results that would support the researcher's claim that mobile aquatic invertebrates can also transfer pollen from male to female flowers in the absence of circulating water.

Identification (1 point maximum)	Prediction (1 point maximum)
Number/presence of pollen grains on female flowers OR pollination	More pollen grains transferred/pollination seen in experimental aquarium
Number/presence of fertilized plants/flowers OR fertilization	More fertilized plants/flowers/fertilization seen in experimental aquarium
Number/presence of seed/fruit/offspring produced OR reproduction	More seeds/fruits/offspring produced/reproduction in experimental aquarium

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Question 4

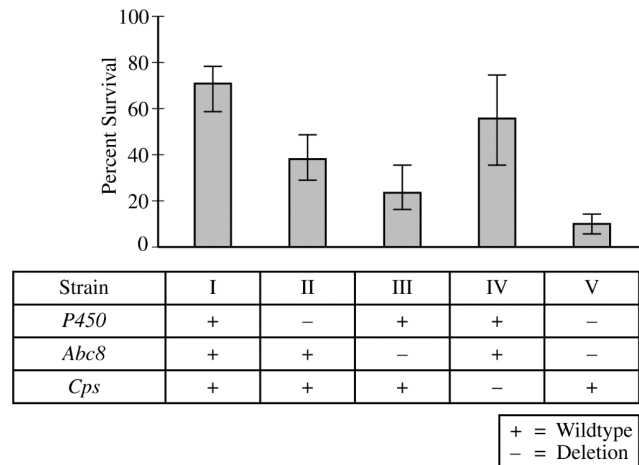


Figure 1. Percent survival of five strains of bedbugs treated with beta-cyfluthrin. A (+) indicates the gene is present; a (–) indicates the gene is deleted. Error bars represent the 95% confidence interval.

The common bedbug (*Cimex lectularius*) is a species of insect that is becoming increasingly resistant to insecticides. Bedbugs possess several genes suspected of contributing to the resistance, including *P450*, *Abc8*, and *Cps*. To investigate the role of these genes in insecticide resistance, researchers deleted one or more of these genes in different strains of bedbugs, as indicated in Figure 1, and treated the strains with the insecticide beta-cyfluthrin. Each strain was genetically identical except for the deleted gene(s) and was equally fit in the absence of beta-cyfluthrin. The percent survival of each strain following beta-cyfluthrin treatment is shown in Figure 1.

- (a) **Identify** the control strain in the experiment. Use the means and confidence intervals in Figure 1 to **justify** the claim that *Abc8* is effective at providing resistance to beta-cyfluthrin.

Identification (1 point)

- Strain I

Justification (1 point)

- Error bars/CIs from strain I/control/WT do not overlap with strain III/*Abc8* deleted strain.
- Mean % survival of strain III/*Abc8* deletion falls outside the 95% confidence interval of strain I/control/WT.
- Strain III/*Abc8* deletion shows a statistically significant difference from strain I/control.

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Question 4 (continued)

- (b) *P450* encodes an enzyme that detoxifies insecticides. *Abc8* encodes a transporter protein that pumps insecticides out of cells. *Cps* encodes an external structural protein located in the exoskeleton that greatly reduces the absorption of insecticides. Based on this information and the data in Figure 1, **explain** how a deletion of both *P450* and *Abc8* results in lower survival in bedbugs compared with a deletion of *Cps* only.

Explanation (1 point per row; 2 points maximum)

Strain	<i>P450</i> and <i>Abc8</i>	<i>Cps</i> only	Explanation
V	Deleted	Present	Bedbugs can neither detoxify nor pump out insecticide, which results in a lower chance of bedbug survival.
IV	Present	Deleted	Bedbugs can detoxify and pump out insecticide, which results in a higher chance of bedbug survival.

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Question 5

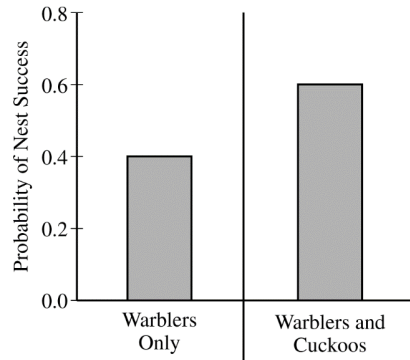


Figure 1. Probability of nest success in an environment with predators

Some birds, including great spotted cuckoos, lay their eggs in the nests of other birds, such as reed warblers. The warbler parents raise the unrelated chicks and provide them with food that would otherwise be given to their biological offspring. A researcher conducted an investigation to determine the type of relationship between warblers and cuckoos in an environment without predators. The researcher found that nests containing only warblers were more likely to be successful than nests containing warblers and cuckoos (data not shown). A successful nest is defined as a nest where at least one chick becomes an adult warbler.

In some geographic areas, several species of nest predators are present. Researchers have found that cuckoo chicks, while in the nest, produce a smelly substance that deters nest predators. The substance does not remain in the nest if cuckoo chicks are removed. Figure 1 shows the probability that nests containing only warblers or containing both warblers and cuckoos will be successful in an environment with predators. In a follow-up experiment, the researchers added cuckoos to a nest that contained only warblers (group 1) and removed cuckoos from a nest containing warblers and cuckoos (group 2).

(a) **Describe** the symbiotic relationship that exists between the cuckoo and warbler in an environment without predators.

Description (1 point)

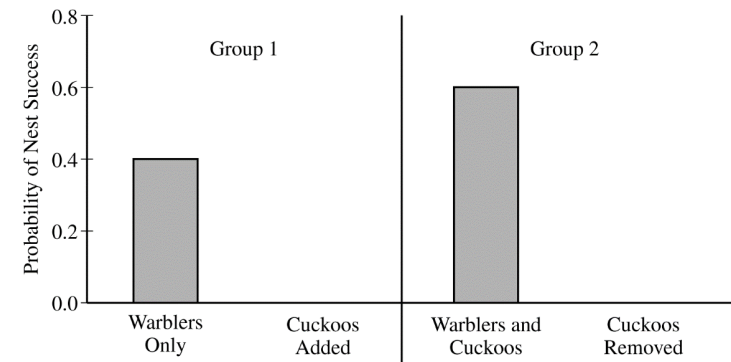
- Cuckoos are parasites (of the warbler).
- The cuckoo benefits from the relationship, and the warbler is harmed by the relationship.

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Question 5 (continued)

(b) On the template provided, **draw** bars in the appropriate locations to predict the relative probability of success for the nest in the presence of predators where:

- the cuckoos were added to the nest containing only warblers (group 1)
- the cuckoos were removed from the nest containing warblers and cuckoos (group 2)

**Graph (2 points)**

- Cuckoo added (group 1): Bar must be HIGHER than the “Warblers Only” bar.
- Cuckoo removed (group 2): Bar must be LOWER than the “Warblers and Cuckoos” bar.

(c) **Identify** the symbiotic relationship that exists between the cuckoo and the warbler in the presence of predators.

Identification (1 point)

- Mutualism
- Both organisms benefit

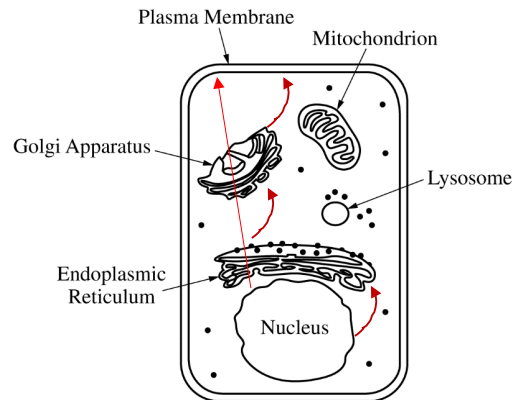
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Question 6

Cystic fibrosis is a genetic condition that is associated with defects in the CFTR protein. The CFTR protein is a gated ion channel that requires ATP binding in order to allow chloride ions (Cl^-) to diffuse across the membrane.

- (a) In the provided model of a cell, **draw** arrows to describe the pathway for production of a normal CFTR protein from gene expression to final cellular location.

Drawing (1 point)



The response must follow this pathway: nucleus/nuclear envelope → endoplasmic reticulum → Golgi apparatus → plasma membrane.

The response may be in the form of a continuous arrow or multiple discontinuous arrows.

- (b) **Identify** the most likely cellular location of the ribosomes that synthesize CFTR protein.

Identification (1 point)

- (Rough) Endoplasmic Reticulum/ER

- (c) **Identify** the most likely cellular location of a mutant CFTR protein that has an amino acid substitution in the ATP-binding site.

Identification (1 point)

- In the (cellular/plasma) membrane

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Question 7

In the tongue sole fish (*Cynoglossus semilaevis*), sex is determined by a combination of genetics and environmental temperature. Genetically male fish have two Z chromosomes (ZZ), and genetically female fish have one Z chromosome and one W chromosome (ZW). When fish are raised at 22°C, ZZ fish develop into phenotypic males and ZW fish develop into phenotypic females. However, when fish are raised at 28°C, the Z chromosome is modified (denoted as Z*). Z*W individuals develop as phenotypic males that are fertile and can pass on the Z* chromosome to their offspring even when the offspring are raised at 22°C. A cross between a ZW female and a Z*Z male is shown in the Punnett square below.

	Z	W
Z*	Z* Z	Z* W
Z	Z Z	Z W

- (a) **Predict** the percent of phenotypic males among the F₁ offspring of the cross shown in the Punnett square if the offspring are raised at 22°C.

Prediction (1 point)

75%

- (b) At least one Z or Z* chromosome is necessary for survival of the fish. A researcher crossed two fish and observed a 2:1 ratio of males to females among the offspring. Based on the information, **identify** the genotype of the male parent in the cross. **Describe** ONE fitness cost to the female of mating with this particular male.

Identification (1 point)

Z* W

Description (1 point)

- Fewer offspring will develop/survive.
- 1/4 of the offspring are predicted to die.
- Some of her offspring will have the Z* chromosome/all of her male offspring will have a Z* chromosome.

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Question 8

Acetylcholine receptor (AChR) proteins are found at the synapse between neurons and skeletal muscle cells. Acetylcholine released from neurons binds to a specific site on the receptor proteins, which causes an ion channel in the receptors to open and allow sodium ions (Na^+) to enter muscle cells. The resulting depolarization of muscle cells initiates muscle contractions. Another molecule, nicotine, can also bind to certain types of AChR proteins and activate the receptors.

A researcher is investigating two different types of AChR proteins: type 1 and type 2. To determine which stimuli activate the receptors, the researcher exposes muscle cells expressing the different types of receptor proteins to stimuli and observes the results indicated in Table 1.

TABLE 1. RESPONSE OF AChR PROTEINS TO DIFFERENT STIMULI

AChR Protein Type	Acetylcholine	Nicotine
Type 1	+	+
Type 2	+	–

+ indicates activation
– indicates no activation

(a) **Describe** the difference in the structure AND function between AChR type 1 and AChR type 2.

Description (2 points)

Points may be earned from only one row.

Structure (1 point maximum)	Function (1 point maximum)
Binding sites differ in shape/specificity/number	- Differential binding of molecules to type 1 and type 2 receptors - Activated by one (ACh) molecule or both (ACh and nicotine) molecules - No difference in response (both open channels OR both result in depolarization OR both cause muscle contraction)
Differential binding of molecules to type 1 and type 2 receptors	- Activated by one (ACh) or both (ACh and nicotine) molecules - No difference in response (both open channels OR both result in depolarization OR both cause muscle contraction)
Receptors activated by one (ACh) or both (ACh and nicotine) molecules	No difference in response (both open channels OR both result in depolarization OR both cause muscle contraction)

(b) Acetylcholinesterase is an enzyme that breaks down acetylcholine in the synapse. **Describe** the effect of inhibiting acetylcholinesterase on the muscle cells with AChR type 2.

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Question 8 (continued)

Description (1 point)

- Continued activation
- Repeated opening of sodium channels OR repeated depolarization OR muscle spasms