2022

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AP® Biology

Scoring Guidelines

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 $Gs\alpha$, a subunit of the G protein (Figure 1, B). This causes $Gs\alpha$ 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, $Gs\alpha$ hydrolyzes GTP to GDP, thus inactivating adenylyl cyclase and stopping the signal (Figure 1, A).

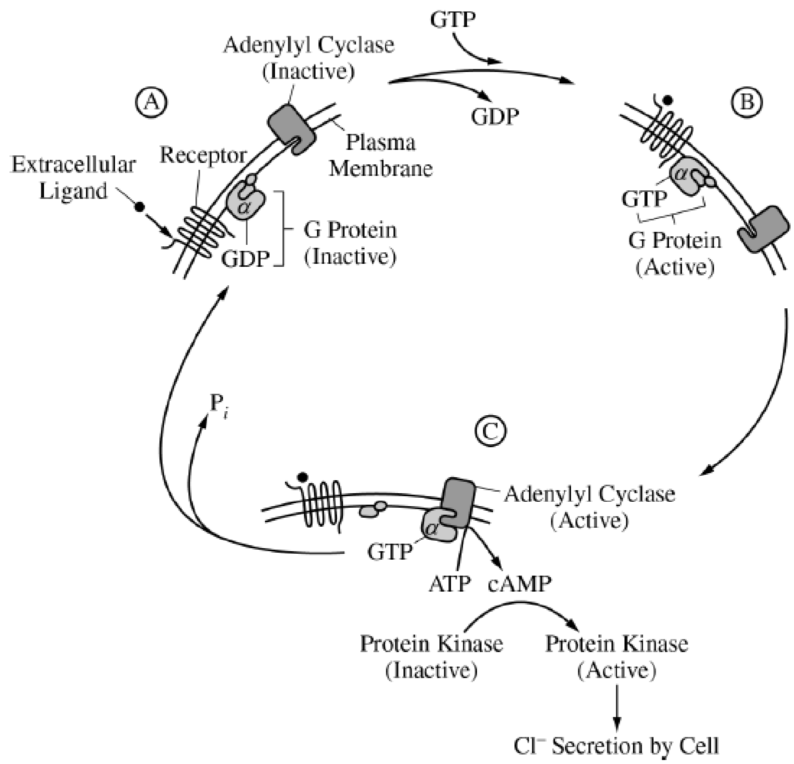


Figure 1. Under normal conditions, ligand binding to a G protein-coupled receptor results in chloride ion transport from an intestinal cell.

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. 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).	**1 point**
	Calculate the percent change in the rate of cAMP production due to the presence of cholera toxin in sample IV compared with sample II. • 1,170% [(127−10)/10 = 11.7 × 100]	**1 point**
	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. • The rate will be 10 (pmol per mg adenyl cyclase per min).	**1 point**
	In a separate experiment, scientists engineer a mutant adenylyl cyclase that cannot be activated by $Gs\alpha$. 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. • (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).	**1 point**
	Total for part (d)	**2 points**
	Total for question 1	**9 points**

Question 2: Interpreting and Evaluating Experimental Results with Graphing

9 points

During meiosis, double-strand breaks occur in chromatids. The breaks are either repaired by the exchange of genetic material between homologous nonsister chromatids, which is the process known as crossing over (Figure 1A), or they are simply repaired without any crossing over (Figure 1B). Plant breeders developing new varieties of corn are interested in determining whether, in corn, a correlation exists between the number of meiotic double-strand chromatid breaks and the number of crossovers.

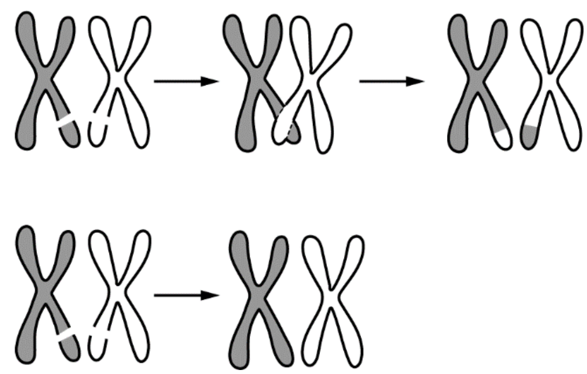


Figure 1. Double-strand breaks in chromatids are repaired with crossing over (A) or without crossing over (B).

Using specialized staining and microscopy techniques, scientists counted the number of double-strand chromatid breaks and the number of crossovers in the same number of meiotic gamete-forming cells of six inbred strains of corn (Table 1).

TABLE 1. NUMBER OF CHROMATID DOUBLE-STRAND BREAKS AND AVERAGE NUMBER OF CROSSOVERS IN INBRED STRAINS OF CORN

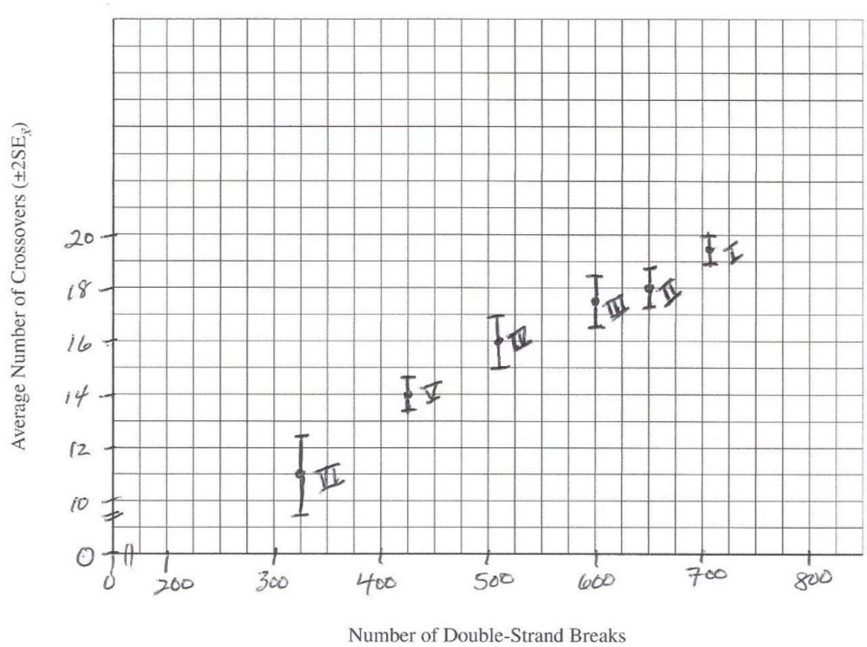
Strain of Corn	Number of Double-Strand Breaks	Average Number of Crossovers ($\pm 2SE_{\bar{X}}$)
I	710	19.5 ± 0.5
II	650	18.0 ± 0.7
III	600	17.5 ± 1.0
IV	510	16.0 ± 1.0
V	425	14.0 ± 0.5
VI	325	11.0 ± 1.5

(a) The double-strand breaks occur along the DNA backbone. **Describe** the process by which the breaks occur. **1 point**

Accept one of the following:

- (Enzymatic) hydrolysis occurs between the sugars and phosphates/nucleotides.
- The covalent bonds between the sugars and phosphates/nucleotides are broken.

(b) Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1 and allows examination of a possible correlation between double-strand breaks and crossovers. **1 point**



- Appropriate axis scaling

Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1 and allows examination of a possible correlation between double-strand breaks and crossovers. **1 point**

- Accurately plotted X,Y graph with separate points for the average number of crossovers for each strain

Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1 and allows examination of a possible correlation between double-strand breaks and crossovers. **1 point**

- Accurate error bars

Based on the data, **determine** whether corn strains I, II, and III differ in their average number of crossovers. **1 point**

- There is no (statistical) difference (in the average number of crossovers) between strains II and III. Strain I is higher/different (in the average number of crossovers) compared with strains II and III.

Total for part (b) **4 points**

(c) Based on the data, **describe** the relationship between the average number of double-strand breaks and the average number of crossovers in the strains of corn analyzed in the experiment. **1 point**

- (In general) there is a direct correlation/positive relationship (between the number of double-strand breaks and the number of chromatid crossovers).

(d)	Crossing over (Figure 1A) creates physical connections that are required for proper separation of homologous chromosomes during meiosis. A diploid cell with four pairs of homologous chromosomes undergoes meiosis to produce four haploid cells. Crossing over occurs between only three of the pairs. **Predict** the number of chromosomes most likely present in each of the four haploid cells. • Two cells will have three/n−1 chromosomes; two cells will have five/n+1 chromosomes.	**1 point**
	Provide reasoning to **justify** your prediction. • During meiosis I, (three homologous pairs separate normally, and) one pair does not separate/experiences nondisjunction. In meiosis II, the sister chromatids separate normally.	**1 point**
	Explain how plant breeders can use the information in Table 1 to help develop new varieties of corn. Accept one of the following: • Because crossing over increases genetic diversity, the plant breeders can breed strains with high crossover numbers/double-strand breaks. • They can increase the number of double-stranded breaks, which may lead to more crossovers that increase genetic variation.	**1 point**
	Total for part (d)	**3 points**
	Total for question 2	**9 points**

Question 3: Scientific Investigation — 4 points

Fireflies emit light when the enzyme luciferase catalyzes a reaction in which its substrate, D-luciferin, reacts to form oxyluciferin and other products (Figure 1). In order to determine the optimal temperature for this enzyme, scientists added ATP to a solution containing D-luciferin, luciferase, and other substances needed for the reaction. They then measured the amount of light emitted during the first three seconds of the reaction when it was carried out at different temperatures.

$$\text{D-Luciferin} + O_2 + \text{ATP} \xrightarrow{\text{Luciferase}} \text{Oxyluciferin} + CO_2 + \text{AMP} + PP_i + \text{Light}$$

Figure 1. Light is emitted as a result of the reaction catalyzed by luciferase.

(a)	**Describe** a characteristic of the luciferase enzyme that allows it to catalyze the reaction. Accept one of the following: • It has an active site/a shape that can bind with the substrate(s)/brings reactants together. • It has a charge that is compatible with the substrate(s).	**1 point**
(b)	**Identify** the dependent variable in the experiment. • The amount of light emitted	**1 point**
(c)	**State** the null hypothesis for the experiment. • Temperature has no effect on the amount of light emitted.	**1 point**
(d)	A student claims that, as temperature increases, there will be an increase in the amount of light given off by the reaction in the first three seconds. **Support** the student's claim. Accept one of the following: • Higher temperature increases the frequency of collisions/interactions between molecules, resulting in an increase in reaction rate. • The higher temperature results in a change to the active site that enhances substrate binding.	**1 point**
	Total for question 3	**4 points**

Question 4: Conceptual Analysis — 4 points

Existing isolated brook trout populations in Newfoundland, Canada, were once part of a larger population that was fragmented at the end of the most recent glaciation period about 10,000 to 12,000 years ago. Researchers investigated 14 naturally separated stream populations of brook trout. They found that the populations are all genetically distinct and show differences in morphology.

(a)	**Describe** the prezygotic barrier that results in these genetically distinct populations. • Geographic isolation prevents gene flow between the populations.	**1 point**
(b)	Brook trout with longer fins are able to swim faster than brook trout with shorter fins. In one of the Newfoundland streams, the main prey of the brook trout evolved to move faster. For brook trout living in this stream, **explain** why there is a difference in fitness between longer-finned individuals and shorter-finned individuals. • Individuals with longer fins are more likely to capture prey and reproduce.	**1 point**
(c)	If two morphologically and behaviorally distinct populations of brook trout remain isolated for many generations, **predict** the likely impact on both populations. Accept one of the following: • The two populations will become separate species. • The two populations will continue diverging (behaviorally/morphologically/ genetically).	**1 point**
(d)	Researchers claim that there are more genetic differences between any two current brook trout populations than there are between any single current population and the ancestral brook trout population from which all the trout are descended. Provide reasoning to **justify** their claim. Accept one of the following: • Each single population has <u>accumulated mutations</u>/<u>experienced genetic drift</u> (distinguishing it from the ancestral population). The mutations each population accumulated are likely to differ (as a result of different selective pressures). • Allele production (as a result of random mutation) and <u>genetic drift</u>/<u>selection by local environmental conditions</u> has resulted in a collection of alleles unique to each population.	**1 point**
	Total for question 4	**4 points**

Question 5: Analyze Model or Visual Representation of a Biological Concept or Process — 4 points

The following models represent all the interacting species in two different communities with some of the same species and feeding relationships. These models assume that both communities have the same initial biomass. The models can be used to understand the effects of human activities on the communities.

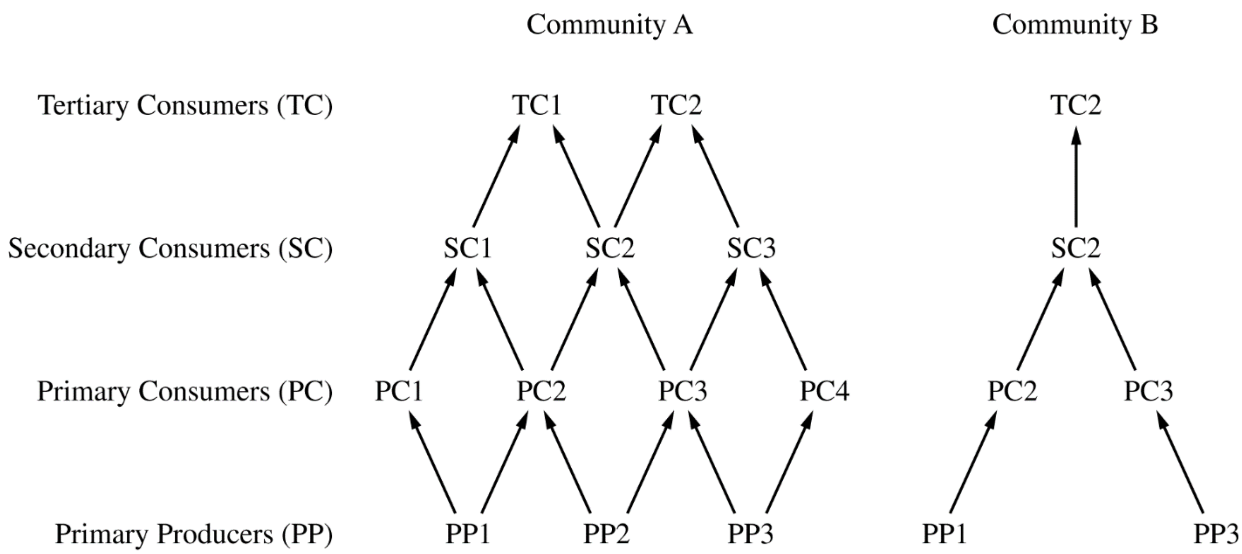
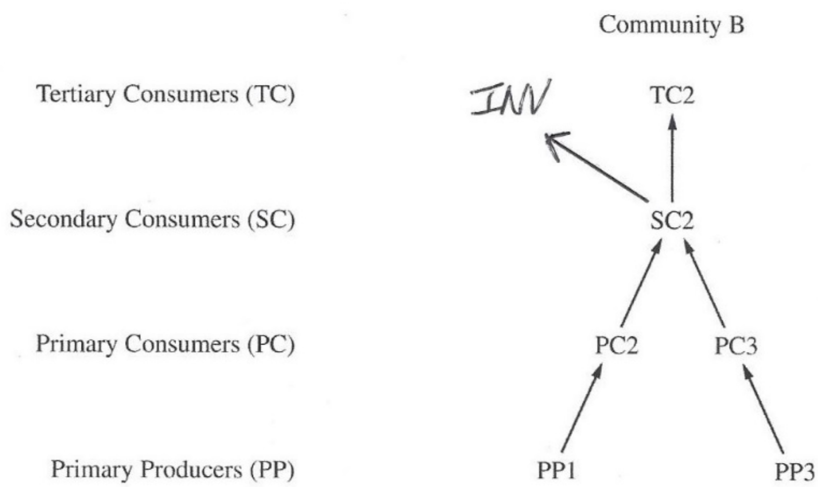


Figure 1. Models of two different communities with some of the same species

(a)	**Describe** a characteristic of a community that makes a species invasive in that community but not invasive in a different community. Accept one of the following: • There are no/reduced numbers of natural predators of the species in the community where it is invasive. • There are no/reduced numbers of competitors of the species in the community where it is invasive. • There are no/reduced numbers of diseases to which the species is susceptible in the community where it is invasive.	**1 point**
(b)	**Explain** why removing species PP1 will have a greater effect on community B than on community A. Accept one of the following: • In community B, there will be decreases in PC2, SC2, and TC2 /PC2, SC2, and PC3. In community A, PC2 has alternative food sources. • With fewer/less diverse primary producers (and primary consumers), there are fewer paths for energy to move through the community. • With fewer species/fewer feeding interactions/less diversity, community B will be less resilient to future environmental change.	**1 point**

(c) An invasive species (INV) that eats individuals of species SC2 is introduced into community B. Using the template in the space provided for your response, for community B, indicate the feeding relationship for this invasive species by correctly placing **INV** to represent the invasive species and **an arrow** to represent the feeding relationship within community B. **1 point**

- INV should be added in a position that is horizontally aligned with TC2. An arrow should point from SC2 to INV.



(d) **Explain** how human activities that add toxins to the soil could change a community with many species at each trophic level, such as community A, into a community with few species at each trophic level, such as community B. **1 point**

Accept one of the following:

- The activities could eliminate primary producers, which reduces species diversity at higher trophic levels.
- The activities could cause biomagnification of the toxins, reducing species diversity at higher trophic levels.

Total for question 5 **4 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 $\pm 2SE_{\bar{X}}$ (hours after introduction into cells)	Total Amount of Protein Translated from mRNA $\pm 2SE_{\bar{X}}$ (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 <u>correlation</u>/<u>relationship</u>.

(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 cap.

(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. 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).	**1 point**
	Total for question 6	**4 points**