From the 2018 Administration

AP CollegeBoard

AP Biology

Practice Exam

NOTE: This is a modified version of the 2018 AP Biology Exam.

This exam may not be posted on school or personal websites, nor electronically redistributed for any reason. This Released Exam is provided by the College Board for AP Exam preparation. Teachers are permitted to download the materials and make copies to use with their students in a classroom setting only. To maintain the security of this exam, teachers should collect all materials after their administration and keep them in a secure location.

Further distribution of these materials outside of the secure College Board site disadvantages teachers who rely on uncirculated questions for classroom testing. Any additional distribution is in violation of the College Board's copyright policies and may result in the termination of Practice Exam access for your school as well as the removal of access to other online services such as the AP Teacher Community and Online Score Reports.

Contents

Note: This publication shows the page numbers that appeared in the ***2017–18 AP Exam Instructions*** book and in the actual exam. This publication was not repaginated to begin with page 1.

Exam Instructions

The following contains instructions taken from the ***2017–18 AP Exam Instructions*** book.

AP Biology Exam

Regularly Scheduled Exam Date: Monday morning, May 14, 2018

Late-Testing Exam Date: Thursday morning, May 24, 2018

Section I	**Total Time:** 1 hour and 30 minutes **Number of Questions:** 69 63 multiple-choice questions plus 6 grid-in questions; 1 hour and 30 minutes. *(The number of questions may vary slightly depending on the form of the exam.)* **Percent of Total Score:** 50% **Writing Instrument:** Pencil required
Section II	**Total Time:** 1 hour and 30 minutes *(10-minute reading period, 1-hour and 20-minute writing period)* **Number of Questions:** 8 questions 2 ten-point questions, 3 four-point questions, and 3 three-point questions **Percent of Total Score:** 50% **Writing Instrument:** Pen with black or dark blue ink

Note: A four-function (with square root), scientific, or graphing calculator may be used on all sections of the AP Biology Exam.

Before Distributing Exams: Check that the title on all exam covers is ***Biology***. If there are any exam booklets with a different title, contact the AP coordinator immediately.

New calculator policy: For the 2018 AP Biology Exam, students may use a four-function (with square root), scientific, or graphing calculator. See pages 49–52 of the *2017-18 AP Coordinator's Manual* for more information.

What Proctors Need to Bring to This Exam

- ☐ Exam packets
- ☐ Answer sheets
- ☐ AP Student Packs
- ☐ *2017-18 AP Coordinator's Manual*
- ☐ This book— *2017-18 AP Exam Instructions*
- ☐ AP Exam Seating Chart template
- ☐ School Code and Homeschool/Self-Study Codes
- ☐ Extra calculators
- ☐ Pencil sharpener
- ☐ Container for students' electronic devices (if needed)
- ☐ Extra No. 2 pencils with erasers
- ☐ Extra pens with black or dark blue ink
- ☐ Lined paper
- ☐ Stapler
- ☐ Watch
- ☐ Signs for the door to the testing room
  - "Exam in Progress"
  - "Cell phones are prohibited during the test administration, including breaks"

SECTION I: Multiple Choice and Grid-In

Before starting the exam administration, make sure each student has an appropriate calculator. If a student does not have a calculator, you may provide one from your supply. If the student does not want to use the calculator you provide or does not want to use a calculator at all, he or she must hand copy, date, and sign the release statement on page 51 of the *2017-18 AP Coordinator's Manual*. Students may have no more than two calculators on their desks. Calculators may not be shared.

› **Do not begin the exam instructions below until you have completed the appropriate General Instructions for your group.**

Make sure you begin the exam at the designated time. Remember, you must complete a seating chart for this exam. See pages 303–304 for a seating chart template and instructions. See the *2017-18 AP Coordinator's Manual* for exam seating requirements (pages 55–58).

If you are giving the regularly scheduled exam, say:
It is Monday morning, May 14, and you will be taking the AP Biology Exam.

If you are giving the alternate exam for late testing, say:
It is Thursday morning, May 24, and you will be taking the AP Biology Exam.

Look at your exam packet and confirm that the exam title is "AP Biology." Raise your hand if your exam packet contains any title other than "AP Biology," and I will help you.

Once you confirm that all students have the correct exams, say:

In a moment, you will open the exam packet. By opening this packet, you agree to all of the AP Program's policies and procedures outlined in the *2017-18 Bulletin for AP Students and Parents*.

You may now remove the shrinkwrap from your exam packet and take out the Section I booklet, but do not open the booklet or the shrinkwrapped Section II materials. Put the white seals aside. . . .

Carefully remove the AP Exam label found near the top left of your exam booklet cover. Place it on page 1 of your answer sheet on the light blue box near the top right corner that reads "AP Exam Label.". . .

If students accidentally place the exam label in the space for the number label or vice versa, advise them to leave the labels in place. They should not try to remove the label; their exam can still be processed correctly.

Listen carefully to all my instructions. I will give you time to complete each step. Please look up after completing each step. Raise your hand if you have any questions.

Give students enough time to complete each step. Don't move on until all students are ready.

Read the statements on the front cover of the Section I booklet. . . .

Sign your name and write today's date. . . .

Now print your full legal name where indicated. . . .

Turn to the back cover of your exam booklet and read it completely. . . .

Are there any questions? . . .

You will now take Section I of the exam. Section I is the multiple-choice and grid-in portion of the exam. You may never discuss the multiple-choice exam content at any time in any form with anyone, including your teacher and other students. If you disclose the multiple-choice exam content through any means, your AP Exam score will be canceled.

For the multiple-choice questions, the answer sheet has circles marked A–E for each question. For Biology, you will use only the circles marked A–D. You must complete the answer sheet using a No. 2 pencil only. Open your answer sheet to page 2. Mark all of your responses beginning on page 2 of your answer sheet, one response per question. No credit will be given for anything written in the exam booklet. Scratch paper is not allowed, but you may use the margins or any blank space in the exam booklet for scratch work. If you need to erase, do so carefully and completely. Your score on the multiple-choice section will be based solely on the number of questions answered correctly. You may use a four-function (with square root), scientific, or graphing calculator.

For the grid-in questions, you will solve each problem, write your final numeric answer in the boxes at the top of the grid, and fill in the corresponding circles. Enter your responses for the grid-in questions on page 3 of the answer sheet beginning with number 121. You will receive credit only if the circles are filled in correctly. Please pay close attention to the directions in your exam booklet for completing the grid-in questions.

Are there any questions? . . .

You have 1 hour and 30 minutes for this section. Open your Section I booklet and begin.

Note Start Time _____. Note Stop Time _____.

Check that students are marking their answers in pencil on their answer sheets and that they are not looking at their shrinkwrapped Section II booklets.

After 1 hour and 20 minutes, say:

There are 10 minutes remaining.

After 10 minutes, say:

Stop working. Close your booklet and put your answer sheet on your desk, faceup. Make sure you have your AP number label and an AP Exam label on page 1 of your answer sheet. Sit quietly while I collect your answer sheets.

Collect an answer sheet from each student. Check that each answer sheet has an AP number label and an AP Exam label.

After all answer sheets have been collected, say:

Now you must seal your exam booklet using the white seals you set aside earlier. Remove the white seals from the backing and press one on each area of your exam booklet cover marked "PLACE SEAL HERE." Fold each seal over the back cover. When you have finished, place the booklet on your desk, faceup. I will now collect your Section I booklet. . . .

Collect a Section I booklet from each student. Check that each student has signed the front cover of the sealed Section I booklet.

There is a 10-minute break between Sections I and II.

When all Section I materials have been collected and accounted for and you are ready for the break, say:

Please listen carefully to these instructions before we take a 10-minute break. All items you placed under your chair at the beginning of this exam must stay there, and you are not permitted to open or access them in any way. Leave your shrinkwrapped Section II packet on your desk during the break. You are not allowed to consult teachers, other students, notes, or textbooks during the break. You may not make phone calls, send text messages, use your calculators, check email, use a social networking site, or access any electronic or communication device. Remember, you may never discuss the multiple-choice exam content with anyone, and if you disclose the content through any means, your AP Exam score will be canceled. Are there any questions? . . .

You may begin your break. Testing will resume at _____ .

SECTION II: Free Response

After the break, say:

May I have everyone's attention? Place your Student Pack on your desk. . . .

You may now remove the shrinkwrap from the Section II packet, but do not open the exam booklet until you are told to do so. . . .

Read the bulleted statements on the front cover of the exam booklet. Look up when you have finished. . . .

Now take an AP number label from your Student Pack and place it on the shaded box. If you don't have any AP number labels, write your AP number in the box. Look up when you have finished. . . .

Read the last statement. . . .

Using your pen, print the first, middle, and last initials of your legal name in the boxes and print today's date where indicated. This constitutes your signature and your agreement to the statements on the front cover. . . .

Turn to the back cover and, using your pen, complete Item 1 under "Important Identification Information." Print the first two letters of your last name and the first letter of your first name in the boxes. Look up when you have finished. . . .

In Item 2, print your date of birth in the boxes. . . .

In Item 3, write the school code you printed on the front of your Student Pack in the boxes. . . .

Read Item 4. . . .

Are there any questions? . . .

If this is your last AP Exam, you may keep your Student Pack. Place it under your chair for now. Otherwise I will collect all Student Packs. . . .

Read the information on the back cover of the exam booklet. Do not open the booklet until you are told to do so. Look up when you have finished. . . .

Collect the Student Packs.

Then say:

Are there any questions? . . .

The total Section II time is 1 hour and 30 minutes. This includes a 10-minute reading period. The reading period is designed to provide you with time to develop thoughtful, well-organized responses. You are advised to spend the 10-minute period reading all the questions, and to use the unlined pages to sketch graphs, make notes, and plan your answers. The focus of the reading period should be the organization of questions 1 and 2. You may begin writing your exam responses before the reading period is over. You may make notes on the pages that contain the exam questions, but your responses must be written on the designated lined pages using a pen with black or dark blue ink. Are there any questions? . . .

You are responsible for pacing yourself and may proceed freely from one question to the next. Be sure that you answer all of the questions. If you need more paper to complete your responses, raise your hand. At the top of each extra sheet of paper you use, write only:

- **your AP number, and**
- **the question number you are working on.**

You may now open the Section II booklet and begin the 10-minute reading period.

Note Start Time _____ . Note Stop Time _____ .

After 10 minutes, say:

The reading period is over. You have 1 hour and 20 minutes remaining to complete Section II.

Note Start Time _____ . Note Stop Time _____ .

Check that students are using pens to write their answers in their exam booklets.

After 1 hour and 10 minutes, say:

There are 10 minutes remaining.

After 10 minutes, say:

Stop working and close your exam booklet. Place it on your desk, faceup.

If any students used extra paper for a question in the free-response section, have those students staple the extra sheet(s) to the first page corresponding to that question in their exam booklets. Complete an Incident Report after the exam (see page 67 of the *2017-18 AP Coordinator's Manual* for complete details).

Then say:

Remain in your seat, without talking, while the exam materials are collected. . . .

Collect a Section II exam booklet from each student. Check for the following:

- Exam booklet front cover: The student placed an AP number label on the shaded box and printed their initials and today's date.
- Exam booklet back cover: The student completed the "Important Identification Information" area.

When all exam materials have been collected and accounted for, return to students any electronic devices you may have collected before the start of the exam.

If you are giving the regularly scheduled exam, say:

You may not discuss or share the free-response exam content with anyone unless it is released on the College Board website in about two days. Your AP Exam score results will be available online in July.

If you are giving the alternate exam for late testing, say:

None of the content in this exam may ever be discussed or shared in any way at any time. Your AP Exam score results will be available online in July.

If any students completed the AP number card at the beginning of this exam, say:

Please remember to take your AP number card with you. You will need the information on this card to view your scores and order AP score reporting services online.

Then say:

You are now dismissed.

After-Exam Tasks

Be sure to give the completed seating chart to the AP coordinator. Schools must retain seating charts for at least six months (unless the state or district requires that they be retained for a longer period of time). Schools should not return any seating charts in their exam shipments unless they are required as part of an Incident Report.

NOTE: If you administered exams to students with accommodations, review the *2017-18 AP Coordinator's Manual* and the *2017-18 AP SSD Guidelines* for information about completing the NAR form, and returning these exams.

The exam proctor should complete the following tasks if asked to do so by the AP coordinator. Otherwise, the AP coordinator must complete these tasks:

- Complete an Incident Report for any students who used extra paper for the free-response section. (Incident Report forms are provided in the coordinator packets sent with the exam shipments.) **These forms must be completed with a No. 2 pencil.** It is best to complete a single Incident Report for multiple students per exam subject, per administration (regular or late testing), as long as all required information is provided. Include all exam booklets with extra sheets of paper in an Incident Report return envelope (see page 67 of the *2017-18 AP Coordinator's Manual* for complete details).
- Return all exam materials to secure storage until they are shipped back to the AP Program. (See page 26 of the *2017-18 AP Coordinator's Manual* for more information about secure storage.) Before storing materials, check the "School Use Only" section on page 1 of the answer sheet and:
  - Fill in the appropriate section number circle in order to access a separate AP Instructional Planning Report (for regularly scheduled exams only) or subject score roster at the class section or teacher level. See "Post-Exam Activities" in the *2017-18 AP Coordinator's Manual*.
  - Check your list of students who are eligible for fee reductions and fill in the appropriate circle on their registration answer sheets.

Student Answer Sheet for the Multiple-Choice and Grid-In Section

Use this section to capture student responses. (Note that the following answer sheet is a sample, and may differ from one used in an actual exam.)

Section I:
Multiple-Choice and Grid-In Questions

This is the multiple-choice and grid-in section of the 2018 AP Exam. It includes cover material and other administrative instructions to help familiarize students with the mechanics of the exam. (Note that future exams may differ in look from the following content.)

For purposes of test security and/or statistical analysis, some questions have been removed from the version of the exam that was administered in 2018. Therefore, the timing indicated here may not be appropriate for a practice exam.

AP® Biology Exam

SECTION I: Multiple Choice and Grid-In

2018

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
1 hour and 30 minutes
Number of Questions
58
Percent of Total Score
50%
Writing Instrument
Pencil required
Electronic Device
Calculator allowed

Instructions

Section I of this exam contains 53 multiple-choice questions and 5 grid-in questions. Indicate all of your answers to the Section I questions on the answer sheet. No credit will be given for anything written in this exam booklet, but you may use the booklet for notes or scratch work.

For questions 1 through 53, after you have decided which of the suggested answers is best, completely fill in the corresponding circle on the answer sheet. Fill in only the circles for questions 1 through 53. Because this section offers only four answer options for each question, do not mark the (E) answer circle for any question.

Give only one answer to each question. If you change an answer, be sure that the previous mark is erased completely. Here is a sample question and answer.

Sample Question	Sample Answer
Chicago is a (A) state (B) city (C) country (D) continent	Ⓐ ● Ⓒ Ⓓ Ⓔ

For questions 121 through 125, follow the instructions after question 53 to enter your numeric answers. Write your numeric answer in the boxes at the top of the grid and fill in the corresponding circles for questions 121 through 125.

Use your time effectively, working as quickly as you can without losing accuracy. Do not spend too much time on any one question. Go on to other questions and come back to the ones you have not answered if you have time. It is not expected that everyone will know the answers to all of the multiple-choice questions.

Your total score on Section I is based only on the number of questions answered correctly. Points are not deducted for incorrect answers or unanswered questions.

Form I
Form Code 4OBP4-S

AP® BIOLOGY EQUATIONS AND FORMULAS

Statistical Analysis and Probability

Mean

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Standard Deviation

$$s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$$

Standard Error of the Mean

$$SE_{\bar{x}} = \frac{s}{\sqrt{n}}$$

Chi-Square

$$\chi^2 = \sum \frac{(o-e)^2}{e}$$

Chi-Square Table

p value	Degrees of Freedom							
	1	2	3	4	5	6	7	8
0.05	3.84	5.99	7.82	9.49	11.07	12.59	14.07	15.51
0.01	6.64	9.21	11.34	13.28	15.09	16.81	18.48	20.09

$\bar{x}$ = sample mean

n = size of the sample

s = sample standard deviation (i.e., the sample-based estimate of the standard deviation of the population)

o = observed results

e = expected results

Degrees of freedom are equal to the number of distinct possible outcomes minus one.

Laws of Probability

If A and B are mutually exclusive, then:

$$P(\text{A or B}) = P(\text{A}) + P(\text{B})$$

If A and B are independent, then:

$$P(\text{A and B}) = P(\text{A}) \times P(\text{B})$$

Hardy-Weinberg Equations

$p^2 + 2pq + q^2 = 1$

$p + q = 1$

p = frequency of the dominant allele in a population

q = frequency of the recessive allele in a population

Metric Prefixes

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

Mode = value that occurs most frequently in a data set

Median = middle value that separates the greater and lesser halves of a data set

Mean = sum of all data points divided by number of data points

Range = value obtained by subtracting the smallest observation (sample minimum) from the greatest (sample maximum)

Rate and Growth

Rate

$$\frac{dY}{dt}$$

Population Growth

$$\frac{dN}{dt} = B - D$$

Exponential Growth

$$\frac{dN}{dt} = r_{max}N$$

Logistic Growth

$$\frac{dN}{dt} = r_{max}N\left(\frac{K-N}{K}\right)$$

Temperature Coefficient Q_{10}

$$Q_{10} = \left(\frac{k_2}{k_1}\right)^{\frac{10}{T_2 - T_1}}$$

Primary Productivity Calculation

$$\frac{\text{mg } O_2}{\text{L}} \times \frac{0.698 \text{ mL}}{\text{mg}} = \frac{\text{mL } O_2}{\text{L}}$$

$$\frac{\text{mL } O_2}{\text{L}} \times \frac{0.536 \text{ mg C fixed}}{\text{mL } O_2} = \frac{\text{mg C fixed}}{\text{L}}$$

(at standard temperature and pressure)

dY = amount of change

dt = change in time

B = birth rate

D = death rate

N = population size

K = carrying capacity

r_{max} = maximum per capita growth rate of population

T_2 = higher temperature

T_1 = lower temperature

k_2 = reaction rate at T_2

k_1 = reaction rate at T_1

Q_{10} = the factor by which the reaction rate increases when the temperature is raised by ten degrees

Water Potential (Ψ)

$\Psi = \Psi_P + \Psi_S$

Ψ_P = pressure potential

Ψ_S = solute potential

The water potential will be equal to the solute potential of a solution in an open container because the pressure potential of the solution in an open container is zero.

The Solute Potential of a Solution

$\Psi_S = -iCRT$

i = ionization constant (this is 1.0 for sucrose because sucrose does not ionize in water)

C = molar concentration

R = pressure constant (R = 0.0831 liter bars/mole K)

T = temperature in Kelvin (°C + 273)

Surface Area and Volume

Volume of a Sphere

$$V = \frac{4}{3}\pi r^3$$

Volume of a Rectangular Solid

$V = \ell wh$

Volume of a Right Cylinder

$V = \pi r^2 h$

Surface Area of a Sphere

$A = 4\pi r^2$

Surface Area of a Cube

$A = 6s^2$

Surface Area of a Rectangular Solid

$A = \Sigma$ surface area of each side

r = radius

ℓ = length

h = height

w = width

s = length of one side of a cube

A = surface area

V = volume

Σ = sum of all

Dilution (used to create a dilute solution from a concentrated stock solution)

$C_iV_i = C_fV_f$

i = initial (starting) C = concentration of solute

f = final (desired) V = volume of solution

Gibbs Free Energy

$\Delta G = \Delta H - T\Delta S$

ΔG = change in Gibbs free energy

ΔS = change in entropy

ΔH = change in enthalpy

T = absolute temperature (in Kelvin)

$pH = -\log_{10}[H^+]$

BIOLOGY

Section I
Time—1 hour and 30 minutes
53 Multiple-Choice Questions
5 Grid-In Questions

Directions: Each of the questions or incomplete statements below is followed by four suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

1. Which of the following observations best supports the hypothesis that a large object collided with Earth in a period of time associated with a mass extinction?

   (A) A species found only in Australia resembles a species found only in North America.
   (B) An analysis of radiation reaching Earth from outer space suggests that water might have existed on distant planets.
   (C) A fossil of an extinct species of mammal is found to have morphological characteristics that are similar to those of a living nocturnal mammal.
   (D) Iridium, which is common in meteorites but rare on Earth, is found in sedimentary rock that contains the last appearance of many species in the fossil record.

2. Which of the following observations best represents a mutualistic relationship?

   (A) Some bacteria and fungi obtain their nutrients by enzymatically digesting larger organisms.
   (B) Chloroplasts in green algae provide sugars for use in cellular metabolism.
   (C) Hermit crabs utilize empty sea snail shells to protect themselves from predators.
   (D) Flowers produce nectar that bees gather to make honey, and in the process the bees pollinate the flowers.

GO ON TO THE NEXT PAGE.

3. A blue-flowered African violet of unknown ancestry self-pollinated and produced 50 seeds. These seeds germinate and grow into flowering plants. Of these plants, 36 produce blue flowers and 14 produce pink flowers. What is the best explanation for the pink-flowered offspring?

   (A) Blue flowers are incompletely dominant to pink flowers.
   (B) Pink flower color is a trait recessive to blue flower color.
   (C) Pink flower color is the result of somatic mutations in the flower color gene.
   (D) A previous generation of the blue-flowered parent must have included 50 percent pink-flowered plants.

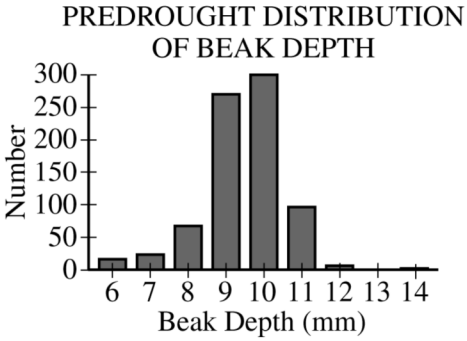
4. While there is only one species of Galápagos Island tortoise, there are several subspecies. Larger islands with more wet highlands have lush vegetation near the ground. Tortoises there tend to have high-domed shells and shorter necks, which restrict upward head movement. They also have shorter limbs. They are the heaviest and largest of the subspecies.

   Smaller, drier islands are inhabited by tortoises with longer necks and limbs and with shells that are elevated above the neck, which allow them to browse taller vegetation.

   Based on the information given, which of the following is a plausible explanation for the ancestry of the tortoise subspecies?

   (A) The subspecies share a recent common ancestor whose neck length, shell shape, and leg length were intermediate between the two subspecies.
   (B) The tortoises with shorter legs and necks were most easily preyed on as young animals by the rats that were introduced, so they survived only on a few islands.
   (C) Random mutations coupled with the inheritance of acquired characteristics resulted in distinct subspecies.
   (D) Individuals with different adaptations in shell shape and leg length best exploited the food resources and left more surviving offspring on each island.

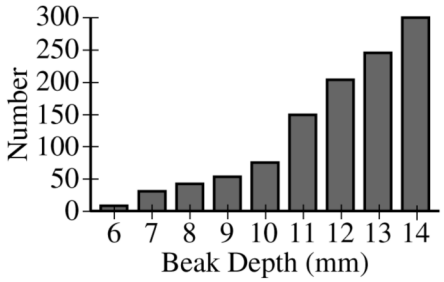
GO ON TO THE NEXT PAGE.



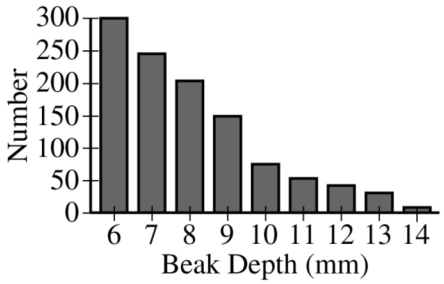
5. The graph above shows the distribution of beak depth in a finch population that had been living on an island under conditions of normal rainfall. During a subsequent drought, the small seeds normally eaten by the finches were less available. Most of the available seeds were large seeds that could be eaten most easily by finches with deep beaks.

   Which of the following graphs best predicts the distribution of beak depth in the finch population after several years of drought?

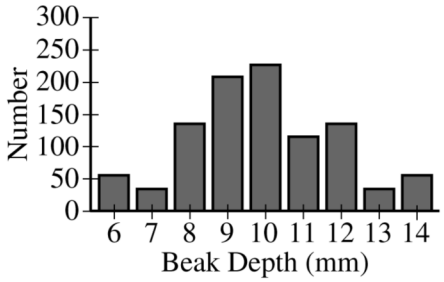
(A)



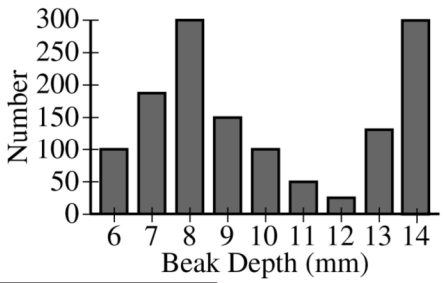
(B)



(C)



(D)



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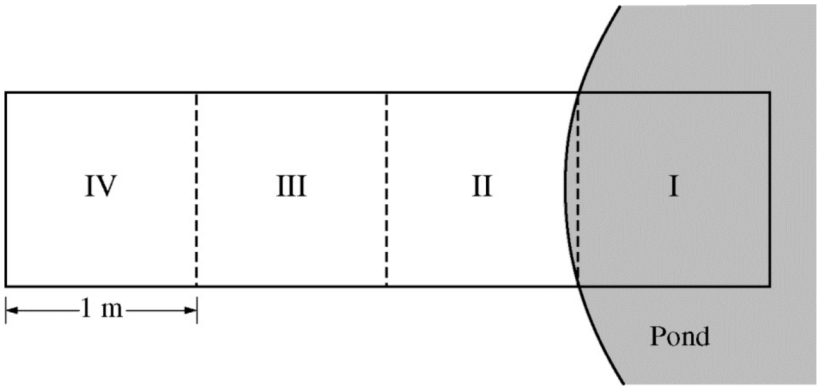
Questions 6-10

Researchers investigated the habitat preferences of two species of garter snakes, *Thamnophis sirtalis* and *Thamnophis atratus*. To create a choice chamber, the researchers built a meshed enclosure and positioned one end of the enclosure at the edge of a small pond. Zone I of the enclosure was located in the water, whereas zone IV of the enclosure was located 2–3 meters away from the water, as represented in the figure below. Snakes inside the enclosure were able to move freely between zones.



In a series of experiments, the researchers introduced a single snake into zone IV of the enclosure at 7:00 A.M. The researchers recorded the location of the snake at six time points throughout the day. In a related experiment, the researchers introduced two snakes, one of each species, into the enclosure at the same time and observed the location of each of the two snakes at the same six time points as before. The researchers repeated both the one-snake and two-snake experiments using different individual snakes of each species. The results are presented in the table.

ZONES MOST FREQUENTLY OCCUPIED BY GARTER SNAKES IN A MESHED ENCLOSURE

	Species Introduced Inside the Meshed Enclosure			
	T. atratus Only	*T. sirtalis* Only	*T. atratus* and *T. sirtalis*	
Time of Day	Zone Most Frequently Occupied by *T. atratus*	Zone Most Frequently Occupied by *T. sirtalis*	Zone Most Frequently Occupied by *T. atratus*	Zone Most Frequently Occupied by *T. sirtalis*
8:00 A.M.	I	II	III	II
10:00 A.M.	II	I	II	II
12:00 P.M.	I	I	III	I
2:00 P.M.	I	I	IV	I
4:00 P.M.	II	I	IV	I
6:00 P.M.	II	II	IV	I

GO ON TO THE NEXT PAGE.

6. Based on the data in the table, which of the following best describes the habitat preference of *T. atratus* when introduced alone inside the meshed enclosure?

   (A) *T. atratus* exhibited equal preferences for all four zones.
   (B) *T. atratus* exhibited a preference for the zones in or near water.
   (C) *T. atratus* exhibited a preference for the zones most distant from the water.
   (D) *T. atratus* exhibited a preference to remain within the zone in which it was initially introduced.

7. Based on the data in the table, which of the following best predicts the results of a study in which natural populations of *T. atratus* and *T. sirtalis* are observed together in an environment that includes a freshwater pond?

   (A) Neither *T. atratus* nor *T. sirtalis* will be observed near the water.
   (B) *T. atratus* will be observed near the water whether or not *T. sirtalis* is present.
   (C) *T. sirtalis* will be observed near the water whether or not *T. atratus* is present.
   (D) *T. atratus* and *T. sirtalis* will be observed together near the water.

8. Which of the following additions to the experimental design will best help test whether the observed habitat preferences were the result of competition between species?

   (A) Placing two individuals from the same population together inside the enclosure
   (B) Introducing different types of plants into the enclosure together with the snakes
   (C) Doubling the number of repetitions for the experimental treatment with *T. atratus* alone
   (D) Repeating the investigation with an enclosure that is twice as long as the original

9. The researchers discovered that both species of garter snakes feed almost exclusively on amphibians found in or near the pond. Based on the results of the investigation, which of the following is most likely to occur if the amphibians become a limited source of food?

   (A) Individuals of *T. atratus* will no longer prefer to be near the water.
   (B) *T. sirtalis* will shift its food preference to herbivory.
   (C) The reproduction rate of *T. sirtalis* will increase.
   (D) The population size of *T. atratus* will decrease.

10. Both species of garter snakes prey on the California newt, *Taricha torosa*, a small amphibian that produces a potent neurotoxin (TTX) in its skin. However, neither species of garter snake is affected by TTX. The resistance to TTX is associated with mutations in the *SCN4A* gene. Which of the following best supports a claim that TTX resistance arose independently in *T. atratus* and *T. sirtalis* ?

    (A) The stomach contents in fossils of both species include the remains of food items that contained TTX.
    (B) Both species of snakes possess the *SCN4A* gene.
    (C) The two species of snakes have different genetic mutations in the *SCN4A* gene.
    (D) *T. atratus* and *T. sirtalis* are sister species that share many of the same morphological features.

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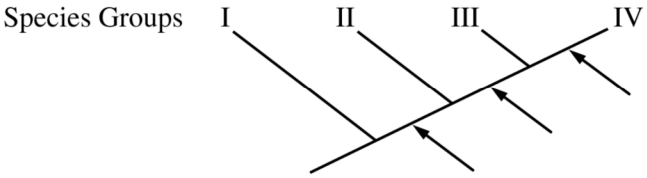
11. Which of the following statements best describes how a growth factor stimulates cell division from outside a cell?

(A) The growth factor binds to other cells in the same area and holds them together to form a large, multicellular structure.
(B) The growth factor binds to receptors on the cell surface, initiating a signal transduction pathway that activates specific target genes.
(C) The growth factor binds to sugar molecules in the extracellular fluid and provides them to the cell as a source of energy.
(D) The growth factor binds to phospholipids in the plasma membrane, creating a channel through which substances enter the cell.

	Derived Characters		
Plant Species	**Vascular Tissue**	**Seeds**	**Flowers**
P	+	+	+
Q	–	–	–
R	+	+	–
S	+	+	+
T	–	–	–
U	+	–	–
W	+	–	–

12. The table above shows the presence (+) or absence (–) of three different derived characters (vascular tissue, seeds, and flowers) for several selected plant species. The cladogram below was created based on the information in the table to represent groups of related species. The presence of the derived characters is indicated with arrows.



Group IV of the cladogram most likely includes which of the following species?

(A) P and S only
(B) Q and T only
(C) R and W only
(D) U and W only

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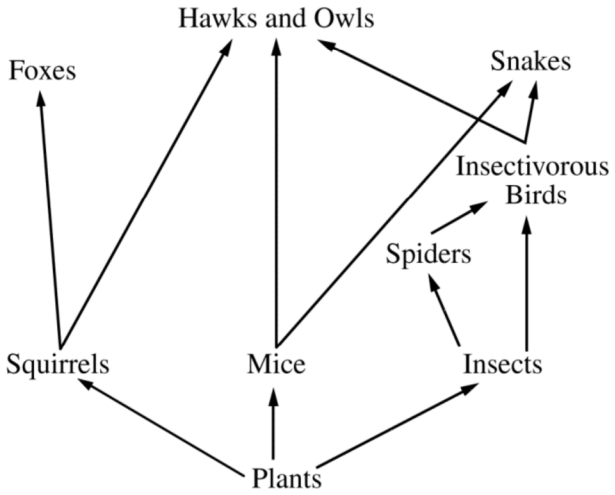
FOOD WEB IN A PARTICULAR
MEADOW COMMUNITY



13. Which of the following changes to the environment will most likely lead to more energy entering the meadow community represented above?

(A) Increasing the number of nesting sites for hawks and owls
(B) Removing squirrels from the area
(C) Increasing the light available to the plants
(D) Applying a chemical pesticide that is specific for spiders

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Questions 14-17

Stickleback fish are found in both marine and freshwater habitats. The marine fish have no scales but have hardened, armorlike plates along their sides. The plates are thought to protect sticklebacks from certain predators.

In the late 1980s, sticklebacks from a marine population colonized Loberg Lake, a freshwater lake in Alaska. Starting in 1990, researchers sampled fish from the lake every four years and recorded the armor-plate phenotypes of the male sticklebacks in each sample. The armor-plate phenotypes were categorized as either complete (plates extending from head to tail), partial (plates extending from head to abdomen), or low (a few plates near the head only). The results are shown in the table below.

ARMOR-PLATE VARIATION IN THE STICKLEBACK POPULATION OF LOBERG LAKE

	Percent of Males in the Sample with Each Armor-Plate Phenotype		
Year	Low	Partial	Complete
1990	1%	2%	97%
1994	45%	14%	41%
1998	58%	16%	26%
2002	76%	15%	9%
2006	90%	6%	4%

14. Which of the following is an independent variable in the investigation?

(A) Year in which the sample was collected
(B) Salinity of the water in Loberg Lake
(C) Size of the stickleback population
(D) Percent of males with each armor-plate phenotype

15. To evaluate the reliability of the results, it would be best to know which of the following?

(A) The surface area of Loberg Lake
(B) The number of males in each sample
(C) The average daily temperature of Loberg Lake
(D) The age of the sticklebacks in each sample

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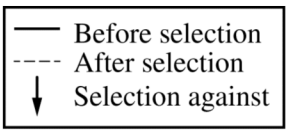
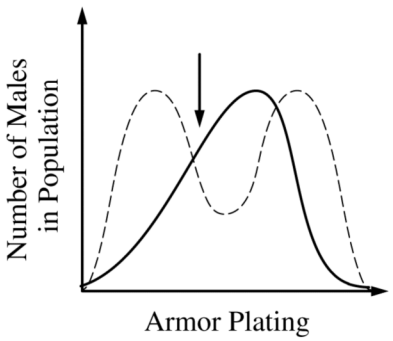
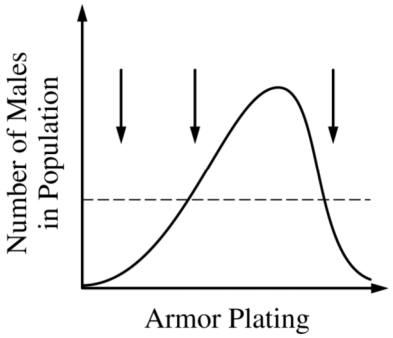
16. Which of the following graphs best represents the type of selection most likely operating in the stickleback population of Loberg Lake?



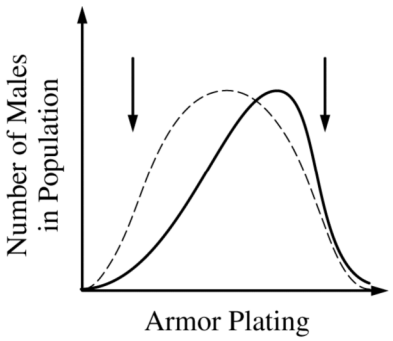
(A)



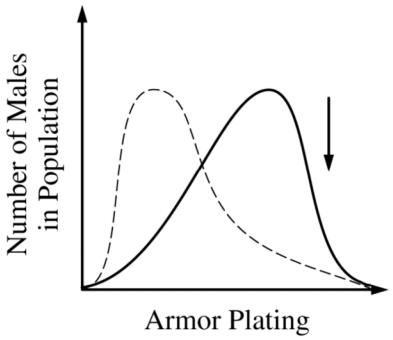
(B)



(C)



(D)



17. Which of the following best explains the changes in the phenotype frequencies of the stickleback population in Loberg Lake?

(A) Predation in the marine environment is different from predation in Loberg Lake.
(B) Marine predators and sticklebacks both colonized Loberg Lake.
(C) Sticklebacks with the partial armor-plate phenotype have the highest rate of reproduction and survival.
(D) The population of sticklebacks in Loberg Lake is subject to genetic drift.

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18. Intact cells of two unknown cell types were placed into solutions with different concentrations of NaCl. Type I cells swelled and burst in the solution with the lowest concentration of NaCl. Type II cells swelled but did not burst in the solution with the lowest concentration of NaCl.

Which of the following descriptions of cell type I and cell type II are most consistent with the data?

	Cell Type I	Cell Type II
(A)	Animal cell surrounded by a plasma membrane only	Plant cell surrounded by a plasma membrane and a cell wall
(B)	Plant cell surrounded by a plasma membrane only	Bacterial cell surrounded by a cell wall only
(C)	Plant cell surrounded by a plasma membrane only	Animal cell surrounded by a plasma membrane and a cell wall
(D)	Animal cell surrounded by a cell wall only	Bacterial cell surrounded by a plasma membrane only

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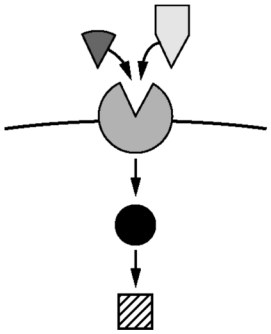
19. In an experiment, a scientist isolates mitochondria from living cells and suspends them in two different buffered solutions. One solution is maintained at pH 4, while the other solution is maintained at pH 9. The scientist finds that mitochondria in the solution at pH 4 continue to produce ATP but those in the pH 9 solution do not.

    The results of the experiment can be used as evidence in support of which of the following scientific claims about mitochondrial activity?

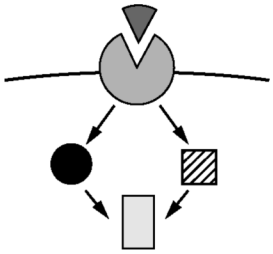
    (A) Mitochondria in a cell-free environment are unable to convert thermal energy into ATP.
    (B) The electron transport chain pumps electrons from the cytosol to the mitochondrial matrix.
    (C) ATP production in mitochondria requires a hydrogen ion gradient that favors movement of protons into the mitochondrial matrix.
    (D) ATP synthase molecules change their orientation in relation to the proton gradient across the mitochondrial membrane.

20. Which of the following best represents two different signaling pathways that share a second messenger?

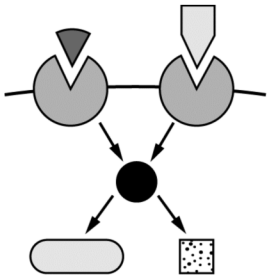
(A)



(B)



(C)



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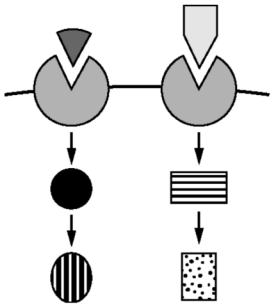

21. Eye color in a particular strain of fly is influenced by one gene with two alleles: a dominant allele that results in red eyes and a recessive allele that results in sepia eyes.

A red-eyed female from a true-breeding population is mated with a sepia-eyed male. The F_1 offspring are all red-eyed. The F_1 flies are allowed to interbreed, producing the following in the F_2 generation.

Females: 40 red eyes; 13 sepia eyes

Males: 39 red eyes; 11 sepia eyes

Which of the following best describes the likely mode of inheritance for the eye-color gene?

(A) The eye-color gene is likely autosomal because males and females have similar phenotype ratios.
(B) The eye-color gene is likely autosomal because more females have sepia eyes than males do.
(C) The eye-color gene is likely sex-linked because the males and females have similar phenotype ratios.
(D) The eye-color gene is likely sex-linked because the males and females display both phenotypes.

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Questions 22-25

Tay-Sachs disease is a rare inherited disorder caused by an autosomal recessive allele of the *HEXA* gene. Affected individuals exhibit severe neurological symptoms and do not survive to reproductive age. Individuals who inherit one copy of the allele (Tay-Sachs carriers) typically show no symptoms of the disorder. The frequencies of Tay-Sachs carriers in the general population of North America and in three different subpopulations are presented in the table.

FREQUENCY OF TAY-SACHS CARRIERS
IN DIFFERENT POPULATIONS

Population	Frequency of Tay-Sachs Carriers
General population	0.004
Subpopulation I	0.037
Subpopulation II	0.035
Subpopulation III	0.020

22. Based on the information presented, which of the following best explains the difference in phenotype between Tay-Sachs carriers and homozygous recessive individuals?

(A) Tay-Sachs carriers received a vaccination that homozygous recessive individuals did not receive.
(B) Tay-Sachs carriers inherited an extra chromosome that homozygous recessive individuals did not inherit.
(C) Tay-Sachs carriers have access to a critical nutrient that homozygous recessive individuals did not inherit.
(D) Tay-Sachs carriers synthesize an essential enzyme that homozygous recessive individuals cannot synthesize.

23. A researcher claims that Tay-Sachs carriers are protected against the infectious disease tuberculosis (TB). Which of the following observations about the annual incidence of tuberculosis in subpopulation II could best be used to support the researcher's claim?

(A) The incidence of TB in subpopulation II is roughly equal to the incidence of TB in the general population.
(B) The incidence of TB in subpopulation II is greater than the incidence of TB in the general population.
(C) The incidence of TB in subpopulation II is lower than the incidence of TB in the general population.
(D) The incidence of TB in subpopulation II is roughly equal to the incidence of Tay-Sachs disease in the general population.

24. Which of the following is an ethical question about Tay-Sachs disease that cannot be answered using scientific methods?

(A) Would a difference in the *HEXA* alleles in subpopulations I and II affect the severity of the neurological symptoms?
(B) Should genetic testing be required before individuals in subpopulation III are advised to not have children?
(C) Could the frequency of Tay-Sachs carriers in subpopulation I be a consequence of a genetic bottleneck?
(D) Should a statistical test be used to evaluate whether the general population is in Hardy-Weinberg equilibrium?

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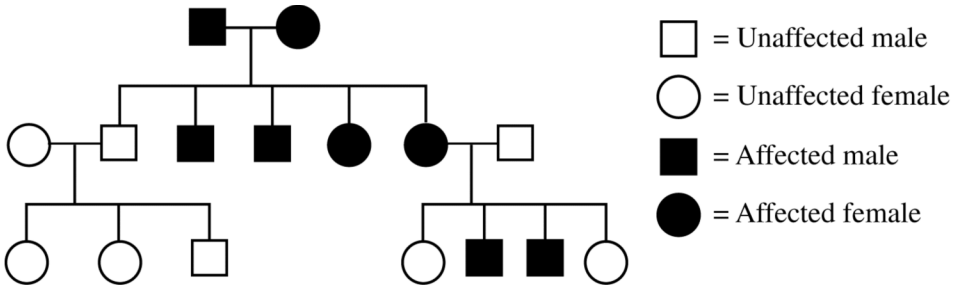
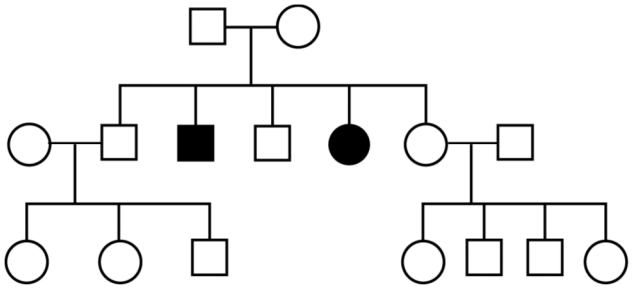
25. Which of the following pedigrees most accurately represents a family with a history of Tay-Sachs disease?

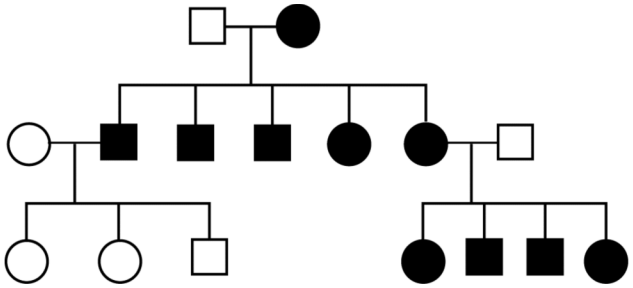
(A)



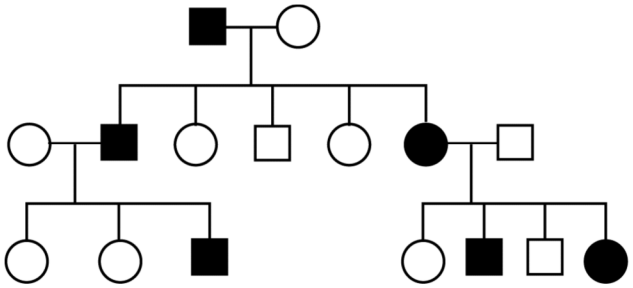
(B)



(C)



(D)

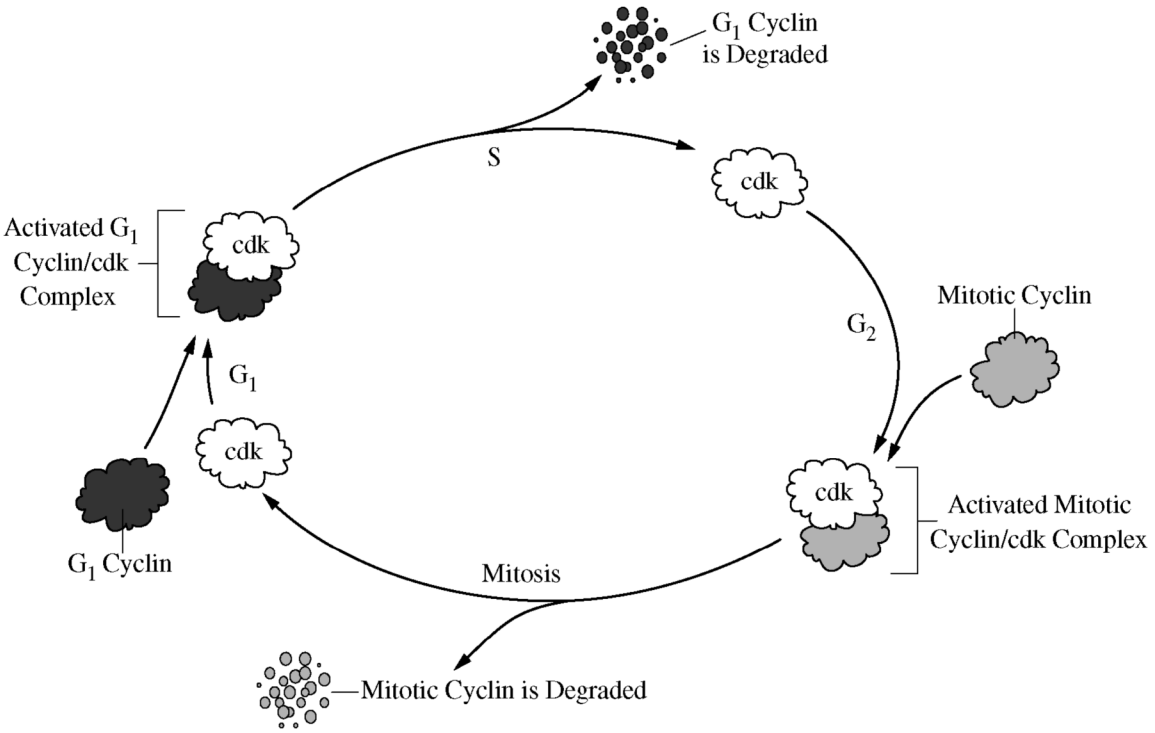


26. Which of the following processes is most likely to occur as a result of an animal cell receiving a signal to initiate apoptosis?

(A) Ribosomes will translate mRNA to produce proteins.
(B) Vesicles will release extracellular growth factors via exocytosis.
(C) Lysosomes will release digestive enzymes into the cytosol.
(D) Vacuoles will fuse with the cellular membrane.

27. In mammals, an increase in the concentration of sodium in the blood triggers the release of antidiuretic hormone (ADH) from the pituitary gland. As the concentration of sodium in the blood returns to previous levels, the release of ADH from the pituitary gland is reduced. Based on the information presented, which of the following describes the most likely role of ADH in maintaining blood osmolarity?

(A) ADH promotes an increase in the movement of sodium into the bloodstream.
(B) ADH promotes an increase in the movement of water into the bloodstream.
(C) ADH promotes an increase in the excretion of water from the body.
(D) ADH promotes an increase in the secretion of additional ADH from the pituitary gland.



28. Based on the model of eukaryotic cell cycle regulation shown in the figure, which of the following best describes the effect of a drug that blocks the production of the mitotic cyclin?

(A) The cell cycle would proceed uncontrollably, and the cell would become cancerous.
(B) The G_1 cyclin would functionally replace mitotic cyclin, and the cell would continue dividing normally.
(C) DNA synthesis would be prevented, and the cell would stop dividing.
(D) The cell would be prevented from entering mitosis, and the cell would stop dividing.

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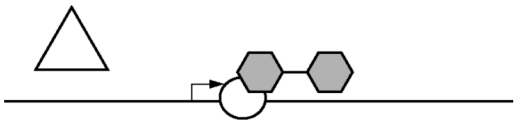
29. The *lac* operon in *E. coli* consists of genes that code for enzymes necessary for the breakdown of lactose. When lactose is absent, the operon is inactive because a repressor protein binds to a specific site in the *lac* operon. When lactose is present, lactose molecules bind to the repressor protein, causing the repressor protein to dissociate from the binding site. In the absence of glucose (a preferred energy source for bacteria), the protein CAP binds to a regulatory site near the *lac* promoter to activate transcription of the *lac* operon.

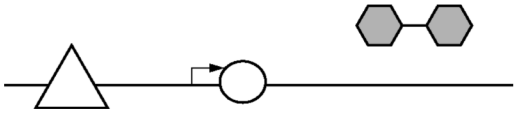
The following symbols represent the macromolecules involved in regulation of the *lac* operon.

In the diagrams below, the horizontal line represents the *lac* operon and the bent arrow represents the transcription start site of the *lac* operon. Which of the following diagrams best represents the scenario in which lactose is available to the cell and glucose is absent?

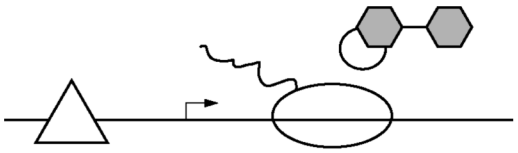
(A)



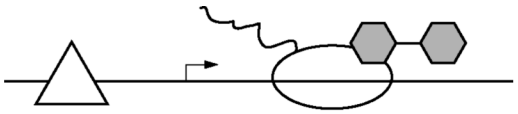
(B)



(C)



(D)



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Questions 30-34

Excess intracellular iron is toxic to cells (iron-induced toxicity). Ferritin is an intracellular iron storage protein that binds excess iron. The presence of ferritin can protect cells from iron-induced toxicity.

In an experiment to investigate the effects of dietary iron intake on ferritin synthesis, rats were given food containing different amounts of iron. Subsequently, the levels of ferritin protein in the liver were measured. The results are shown in Figure 1.

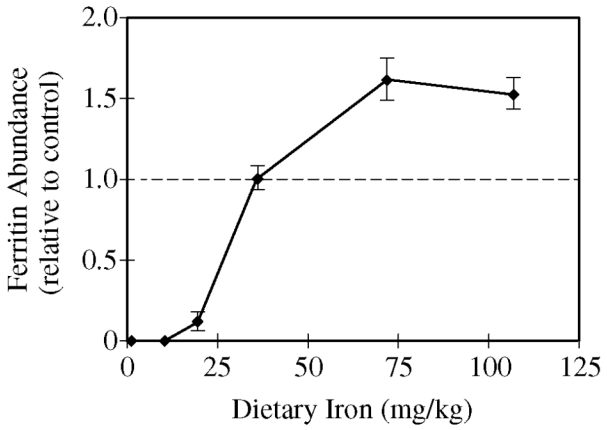

Figure 1. Effects of dietary iron on ferritin levels in rat liver

Based on these and other data, researchers have developed the following model demonstrating how ferritin synthesis is regulated by iron. When iron levels are low, a repressor of translation, iron response protein (IRP), binds to an iron response element (IRE), which is a stem-loop structure near the 5′ end of ferritin mRNA. When iron levels are high, intracellular iron binds to the IRP, and the iron-IRP complex dissociates from the IRE, permitting ribosomes to proceed with the translation of ferritin mRNA. Figure 2 represents the model of the regulation of ferritin mRNA translation by iron.

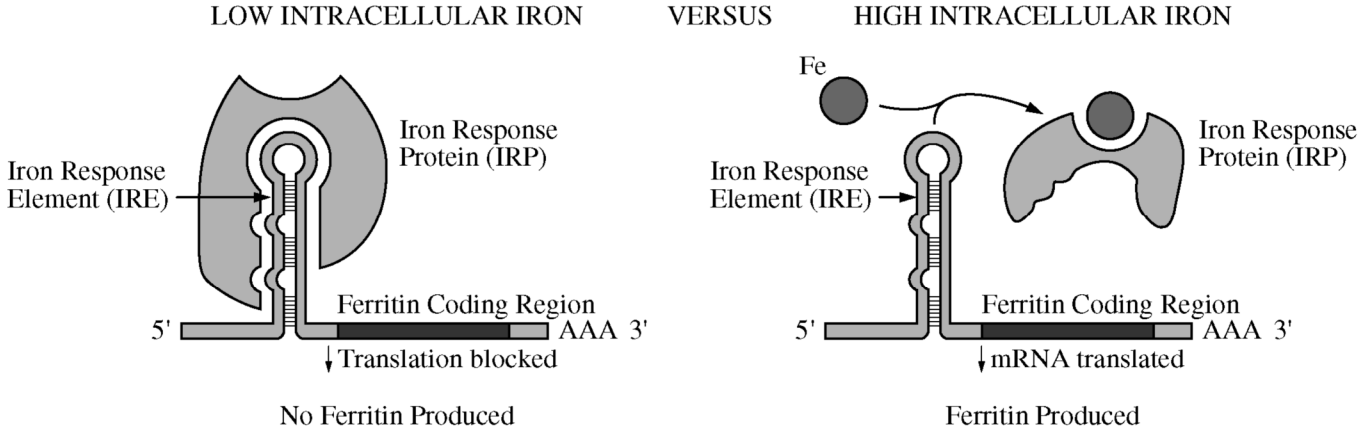

Figure 2. Model of regulation of ferritin synthesis by iron

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30. Based on the data in Figure 1, the concentration of iron in the control diet used in the investigation is most likely within which of the following ranges?

(A) 20–25 mg/kg
(B) 35–40 mg/kg
(C) 70–75 mg/kg
(D) 100–125 mg/kg

31. Which of the following conclusions about dietary iron and ferritin synthesis is best supported by the data in Figure 1 ?

(A) A dietary iron concentration of 25 mg/kg has no effect on ferritin gene expression compared with the control diet.
(B) At a dietary iron concentration of 50 mg/kg, rats make twice as much ferritin as rats fed the control diet do.
(C) Maximum activation of ferritin synthesis occurs at dietary iron concentrations of 75 mg/kg or greater.
(D) The maximum rate of ferritin absorption from the gut occurs at dietary iron concentrations greater than 75 mg/kg.

32. Based on the model of ferritin synthesis presented in Figure 2, which of the following best describes the mechanism whereby iron most likely regulates ferritin production?

(A) Translation occurs under low intracellular iron concentration when the IRP recruits ribosomes to the ferritin mRNA.
(B) Translation occurs under low intracellular iron concentration when the IRP stabilizes the stem-loop structure in the ferritin mRNA.
(C) Translation occurs under high intracellular iron concentration when the IRP-iron complex dissociates from ferritin mRNA, permitting ribosomes access to the ferritin coding region.
(D) Translation occurs under high intracellular iron concentration when the IRP-iron complex brings the 5′ end of the mRNA closer to the ferritin coding region.

33. Based on the model of ferritin synthesis presented in Figure 2, which of the following describes the role of feedback on the control of intracellular iron levels?

(A) A decrease in iron levels activates the IRP. The IRP in turn activates iron transport proteins in the cell membrane, thereby returning free iron levels to normal.
(B) A decrease in iron levels activates synthesis of ferritin protein. Ferritin protein in turn releases bound iron, thereby returning free iron levels to normal.
(C) An increase in iron levels activates the IRP. The IRP in turn binds iron, thereby decreasing both free iron levels and ferritin synthesis.
(D) An increase in iron levels activates synthesis of ferritin protein. Ferritin protein in turn binds iron, thereby decreasing both free iron levels and ferritin synthesis.

34. After a search of nucleotide sequence databases, researchers identified an IRE in the 5′ untranslated region of a gene encoding aconitase, an enzyme involved in the Krebs cycle. Which of the following pieces of experimental evidence best supports the claim that the synthesis of aconitase is controlled by a mechanism similar to ferritin regulation?

(A) IRP binds to aconitase mRNA in the presence of iron.
(B) The relative amount of aconitase protein increases in the presence of high levels of iron.
(C) Oxygen consumption by cells increases in the presence of high levels of iron.
(D) The levels of reduced electron carriers, NADH and $FADH_2$, increase in the presence of high levels of iron.

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35. Retroviruses have an RNA genome. HTLV-1 is a lysogenic retrovirus that establishes a latent infection in human cells. By which of the following mechanisms does infection by a retrovirus such as HTLV-1 most likely cause long-lasting genetic changes to host cells?

(A) The host-cell ribosomes translate the viral RNA genome that enters the cell upon initial viral infection.
(B) The viral RNA polymerase that transcribes host genes has a high error rate.
(C) The RNA viral genome is reverse transcribed into DNA that integrates into the host genome.
(D) The RNA viral genome integrates into the host genome.

36. Which of the following best describes the role of mitosis in the cell cycle?

(A) Distributing replicated chromosomes to daughter nuclei
(B) Dividing the cytoplasm to form four gametes
(C) Producing organelles and replicating chromosomes
(D) Exchanging genetic material between homologous chromosomes

37. A researcher hypothesizes that RNA molecules were present in the most recent common ancestor of all living organisms. Which of the following scientific questions would best test the hypothesis?

(A) Is it possible to produce an RNA polymer in a laboratory setting?
(B) How many distinct functions can a particular RNA molecule perform in a cell?
(C) How many different monomers of RNA are found in a eukaryotic cell?
(D) Do any known organisms function entirely without RNA?

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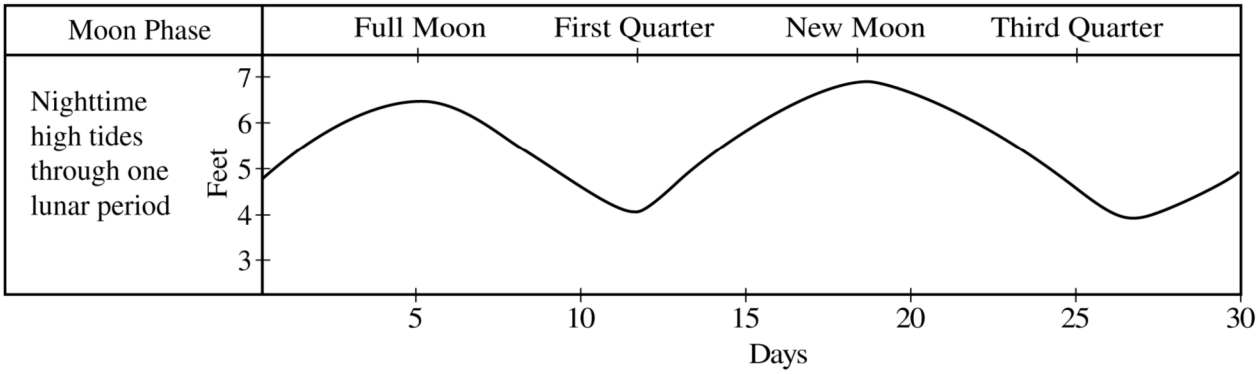

38. The California grunion (*Leuresthes tenuis*) is a small marine fish that lives in shallow waters near the ocean shore. Grunions swim as far onto the beach as possible to mate and lay their eggs (spawn).

A researcher proposes that the spawning behavior takes place when the nighttime tides are highest during the month. Which of the following pieces of evidence would best support the researcher's claim?

(A) Grunion spawning occurs every two weeks during the spawning season.
(B) Grunion spawning occurs when nighttime illumination levels are the lowest.
(C) High tide occurs one time per lunar cycle.
(D) The light intensity of the moon varies within the lunar cycle.

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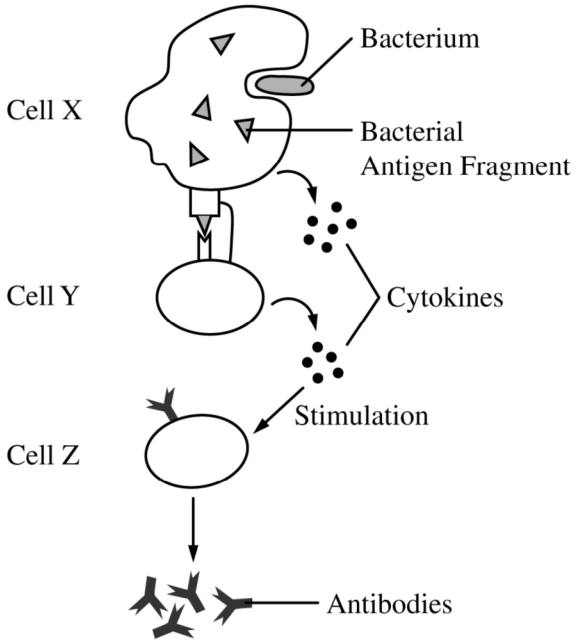
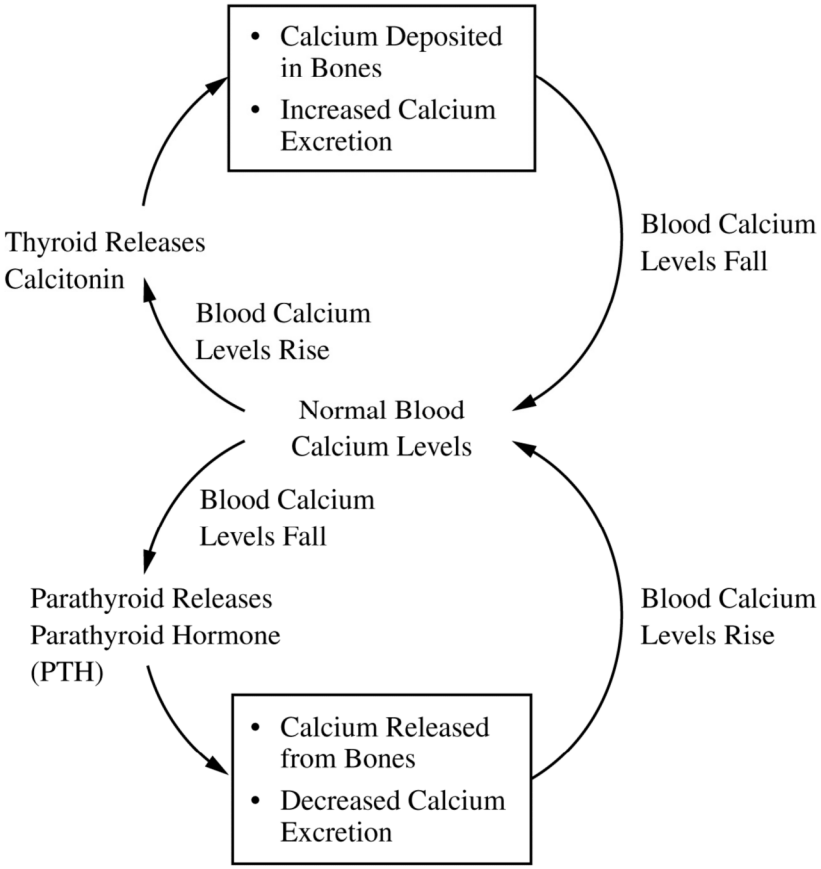


39. The vertebrate immune system consists of multiple types of cells that work together to protect the body from infections as well as from damaged cells. In the immune response represented above, antibodies are synthesized and secreted into the blood and the lymph. The diagram shows the interaction of macrophages, B cells, and helper T cells.

Which of the following correctly labels the cells depicted in the diagram?

	Cell X	Cell Y	Cell Z
(A)	B cells	Macrophages	Helper T cells
(B)	Macrophages	B cells	Helper T cells
(C)	Macrophages	Helper T cells	B cells
(D)	Helper T cells	B cells	Macrophages



40. The model shown in the figure represents the role of two hormones, calcitonin and parathyroid hormone (PTH), in maintaining normal blood calcium levels in humans. If a dietary change results in an increase in blood calcium concentration above normal levels, which of the following is the most likely effect on calcium homeostasis?

(A) Calcitonin levels will decline, thus stimulating the release of PTH.
(B) Calcitonin levels will rise, thus promoting the deposit of calcium into bones.
(C) PTH levels will decline, thus stimulating the loss of calcium from bones.
(D) PTH levels will increase, thus preventing the release of calcitonin.

GO ON TO THE NEXT PAGE.

41. Type 1 diabetes results from the destruction of insulin-producing cells in the pancreas. Individuals with type 1 diabetes produce insufficient amounts of insulin, a hormone that regulates the concentration of glucose in the blood.

    Which of the following best explains how treatment with a drug that stimulates the production of insulin receptors on target cells will affect the insulin signaling pathway in an individual with type 1 diabetes?

    (A) The drug will have little or no effect on the signaling pathway because the receptors will not be activated in the absence of insulin.
    (B) The drug will have little or no effect on the signaling pathway because insulin receptors will not be allowed to enter the cells.
    (C) The drug will restore the function of the signaling pathway because insulin levels will return to normal.
    (D) The drug will restore the function of the signaling pathway because nonpancreatic cells will begin to produce insulin receptors.

42. Which of the following best explains how small molecules move between adjacent cells in a plant shoot?

    (A) The molecules are actively transported by motor proteins along the cytoskeleton.
    (B) The molecules pass freely through plasmodesmata, which are cytoplasmic strands connecting two cells.
    (C) The molecules are swept along in the extracellular fluid by cilia projecting from cell membranes.
    (D) The molecules bind reversibly to receptors on the cell membranes of xylem.

43. Which of the following is most likely to create genetic variation in a population?

    (A) RNA polymerase errors during transcription
    (B) Helicase failure to unwind DNA during DNA replication
    (C) DNA polymerase errors during replication
    (D) Misincorporation of amino acids by tRNA during translation

GO ON TO THE NEXT PAGE.

Questions 44-48

To investigate the influence of predation risk on ray behavior, a student observed and counted the large marine animals swimming in a shallow, nearshore section of a coral reef ecosystem. The time of each observation was recorded relative to the time of high tide. The student noted that at low tide, when the water level is low, many of the large animals are forced out of the study area and into the deeper waters of the outer reef. During high tides, when the water level is high, the large animals are able to reenter the study area.

Over a three-day period, the student observed a total of 604 individual rays belonging to three species: cowtail rays, giant shovelnose rays, and black stingrays. For each ray that was sighted, its body length was estimated and its status as either alone (ungrouped) or found with other rays (grouped) was noted. Occasionally, rays were observed sifting through the sandy substrate of the study area to capture food items such as molluscs and crustaceans. In one instance, an injured ray with bite marks that were likely sustained in a shark attack was sighted. In addition to the rays, the student observed lemon sharks (n = 46) and blacktip reef sharks (n = 39). The results of the study are presented in the figures below.

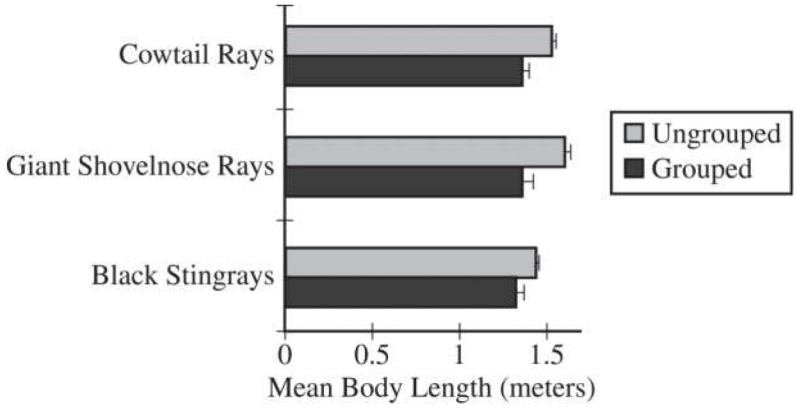


Figure 1. Comparison of mean body lengths of the grouped and ungrouped rays that were observed in a nearshore section of a coral reef ecosystem. Error bars represent $2SE_{\bar{X}}$.

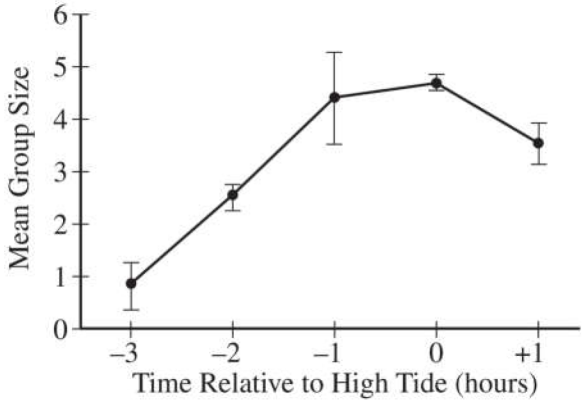


Figure 2. Mean numbers of rays per group in the study area at different stages of the tide cycle. High tide occurs at T = 0 hours.

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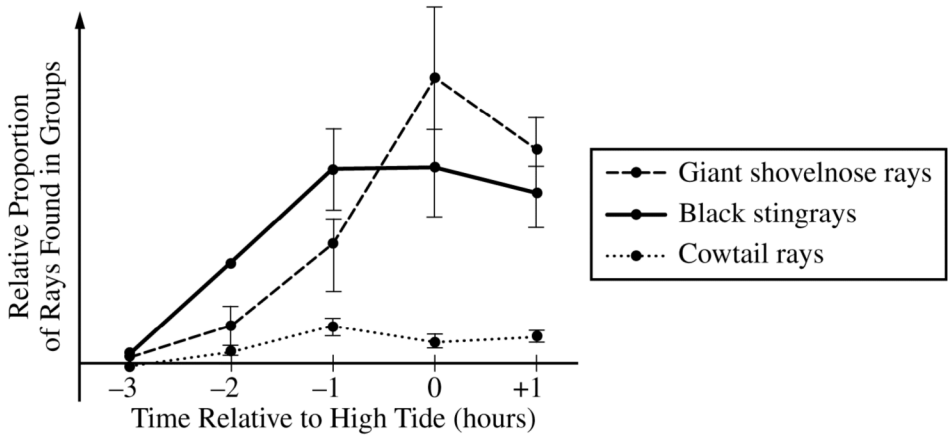


Figure 3. Relative proportions of rays in groups at different stages of the tide cycle for each of the three different populations. High tide occurs at T = 0 hours.

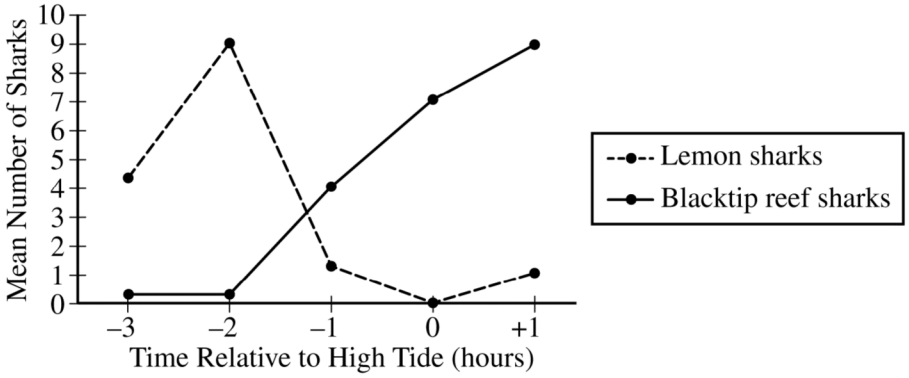


Figure 4. Mean numbers of lemon sharks and blacktip reef sharks in the study area at different stages of the tide cycle. High tide occurs at T = 0 hours.

44. Which of the following scientific claims about the survival strategies used by organisms in a coral reef ecosystem is best supported by the data presented in Figure 1 ?

(A) Smaller members of a vulnerable population are more likely to act collectively.
(B) Smaller members of a vulnerable population are more likely to rely on defensive coloration.
(C) Larger members of a vulnerable population are more likely to exhibit aggression.
(D) Larger members of a vulnerable population are more likely to behave altruistically.

45. Based on the data presented in Figure 2, which of the following behavioral patterns do rays in a coral reef ecosystem typically exhibit three hours before high tide?

(A) Group learning
(B) Mate selection
(C) Solitary foraging
(D) Social interaction

GO ON TO THE NEXT PAGE.

46. Which of the following scientific claims about interacting populations of giant shovelnose rays and blacktip reef sharks is best supported by the results shown in Figures 3 and 4 ?

(A) Some parasitic species cause significant changes in the behavior of their hosts.
(B) Some invasive species outcompete native species for limited resources.
(C) Some migratory species transmit infectious diseases to resident populations.
(D) Some prey species form protective groups in the presence of predators.

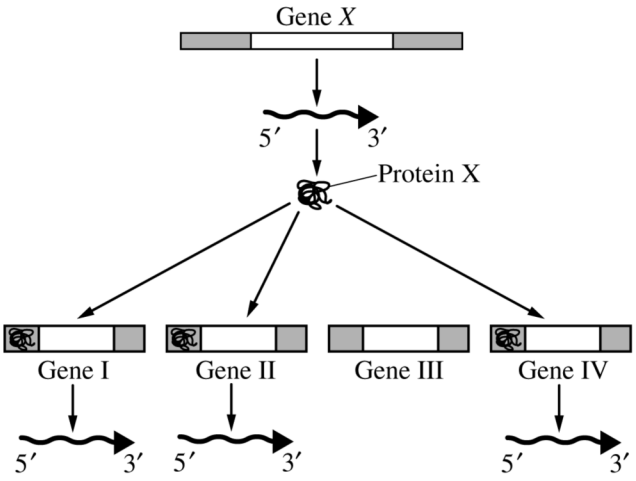
47. Which of the following best justifies the use of the study area to investigate how one species influences the behavior of another?

(A) Black stingrays were present in the study area in the presence and absence of blacktip reef sharks.
(B) Giant shovelnose rays and cowtail rays spent long periods of time at rest while inside the study area.
(C) Natural barriers in the study area prevented lemon sharks from competing with blacktip reef sharks for limited resources.
(D) Cowtail rays in the study area formed groups at some stages of the tide cycle but remained alone at other stages.

48. Based on the results of the study, which of the following is the most likely connection between behavior and evolutionary fitness in a nearshore coral reef environment?

(A) Rays that search for food alone at low tide typically grow to larger sizes than do rays that search for food in groups.
(B) Rays that join groups during rising tides are reproductively more successful than are rays that do not join groups.
(C) Rays that swim far from shore at high tide often encounter a greater variety of species than do rays that remain near the shore.
(D) Rays that roam across large distances during falling tides become stronger swimmers than do rays that spend more time at rest.

49. Phenotype is determined, in part, by which genes are expressed. The diagram below illustrates how the product of gene *X* regulates the expression of other genes.



Which of the following statements best explains how protein X regulates gene expression?

(A) Protein X is responsible for processing pre-mRNA.
(B) Protein X is responsible for activating transcription of some genes but not others.
(C) Protein X is a member of some cytoplasmic protein complexes but not others.
(D) Protein X causes specific base-pair changes to produce new alleles.

50. Two types of cholesterol transport proteins, low-density lipoproteins (LDL) and high-density lipoproteins (HDL), bind to cholesterol and carry it through the bloodstream. Familial hypercholesterolemia (FH) is characterized by high cholesterol levels in the blood, which can lead to cardiovascular disease.

    FH is associated with a loss-of-function mutation of a gene that encodes LDL receptors in liver cells. Individuals who are heterozygous produce lower-than-normal amounts of the LDL receptors, and individuals who are homozygous for the mutant allele have no LDL receptor function.

    Individuals with FH can be treated with drugs that result in increased production of LDL receptors in liver cells. Which of the following best explains the observation that the drugs can effectively control blood cholesterol levels in individuals who are heterozygous but are not effective in individuals homozygous for the mutant allele?

    (A) The drugs repair the mutant allele by copying the wild-type allele.
    (B) The drugs prevent cholesterol from entering the liver cells in individuals who are heterozygous but not in individuals who are homozygous for the mutant allele.
    (C) Cholesterol molecules primarily bind to HDL receptors in individuals with FH.
    (D) There must be at least one copy of the wild-type LDL receptor allele to produce functional LDL receptors.

51. Which of the following groups of cellular components are found in eukaryotic cells but not prokaryotic cells?

(A) Ribosomes, a nucleus, and chloroplasts
(B) Circular chromosomes, mitochondria, and an endoplasmic reticulum
(C) A nucleus, ribosomes, and cell walls
(D) An endoplasmic reticulum, mitochondria, and a nucleus

52. If an individual with diabetes consumes food that is high in simple carbohydrates, blood-sugar levels can rise above normal levels. Which of the following questions would provide the best direction for a researcher who wanted to study the impact of abnormally high blood-sugar levels on cellular homeostasis in diabetics?

(A) Are cells in diabetics larger in size than those in nondiabetics?
(B) Do the cells in diabetics have more potassium ion channels in the cell membrane than the cells in nondiabetics do?
(C) Does water move from cells into blood vessels more rapidly in diabetics than in nondiabetics when blood-sugar levels are higher than normal?
(D) Do the cells of diabetics use simple sugars as an energy source?

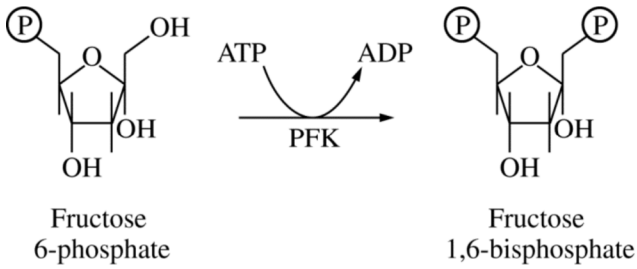


Figure 1. Reaction catalyzed by phosphofructokinase (PFK) during glycolysis

53. Phosphofructokinase (PFK) is an enzyme that catalyzes the conversion of fructose 6-phosphate to fructose 1,6-bisphosphate during glycolysis, as represented in Figure 1.

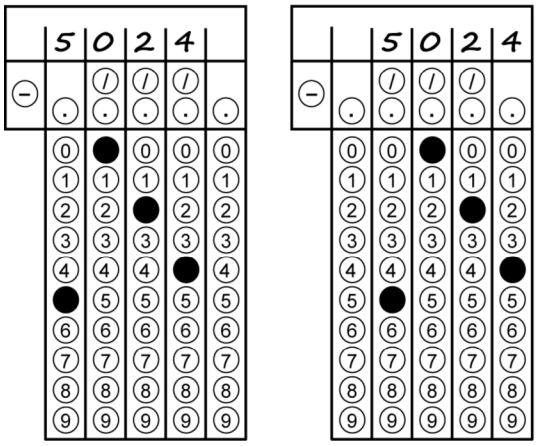
PFK can be allosterically inhibited by ATP at high concentrations. Which of the following is the benefit of regulating glycolysis by the concentration of ATP?

(A) Glycolysis proceeds when the intracellular concentration of ATP is low, which provides ATP to drive cellular reactions.
(B) Glycolysis proceeds when the intracellular concentration of ATP is high and the cell stores ATP for future use.
(C) Glycolysis is inhibited when the intracellular concentration of ATP is low because PFK requires ATP as a substrate for the reaction it catalyzes.
(D) Glycolysis is inhibited when the intracellular concentration of ATP is high because ATP will compete with fructose 1,6-bisphosphate for binding to the active site on the enzyme.

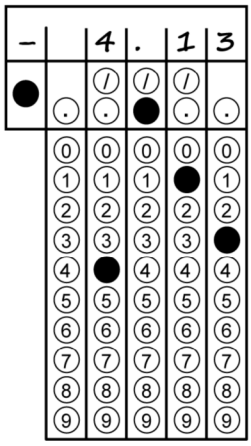
Directions: The next five questions, numbered 121–125, require numeric answers.
Determine the correct answer for each question and enter it in the grid on page 3 of the answer sheet.
Use the following guidelines for entering your answers.

- Start your answer in any column, space permitting. Unused columns should be left blank.
- Write your answer in the boxes at the top of the grid and fill in the corresponding circles. Mark only one circle in any column. You will receive credit only if the circles are filled in completely.
- Provide your answer in the format specified by the question. The requested answer may be an integer, a decimal, or a fraction, and it may have a negative value.
- To enter a fraction, use one of the division slashes to separate the numerator from the denominator, as shown in the example below. Fractions only need to be reduced enough to fit in the grid.
- Do not enter a mixed number, as this will be scored as a fraction. For example, 2 1/2 (two and one-half) will be scored as 21/2 (twenty-one halves).

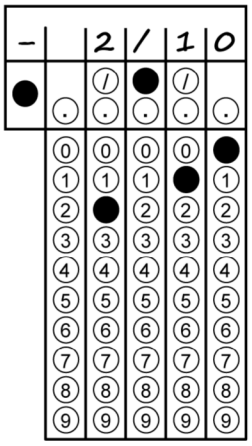
Integer answer: 5024
(either position is correct)



Decimal answer:
−4.13



Fraction answer: −2/10
(does not have
to be reduced)



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121. In a particular variety of corn, kernel color is controlled by a single gene with two alleles. The dominant allele results in purple kernels, and the recessive allele results in yellow kernels. A single corncob may contain hundreds of individual kernels, each of which is the result of a separate fertilization event. Predict the frequency of yellow kernels that result from a cross between two heterozygous plants. Enter your response as a fraction or a decimal to the nearest hundredth.

122. In a certain plant species, a single gene controls the expression of flower color. The gene has two alleles: a dominant allele (*B*) associated with dark-blue flowers and a recessive allele (*b*) associated with light-blue flowers. A researcher is investigating flower-color allele frequencies in a population of the plants. Of the 910 plants in the population, the researcher observes that 347 have light-blue flowers.

    Predict the number of plants in the population that would be expected to have the *Bb* genotype if the population were in Hardy-Weinberg equilibrium. Give your answer to the nearest whole number.

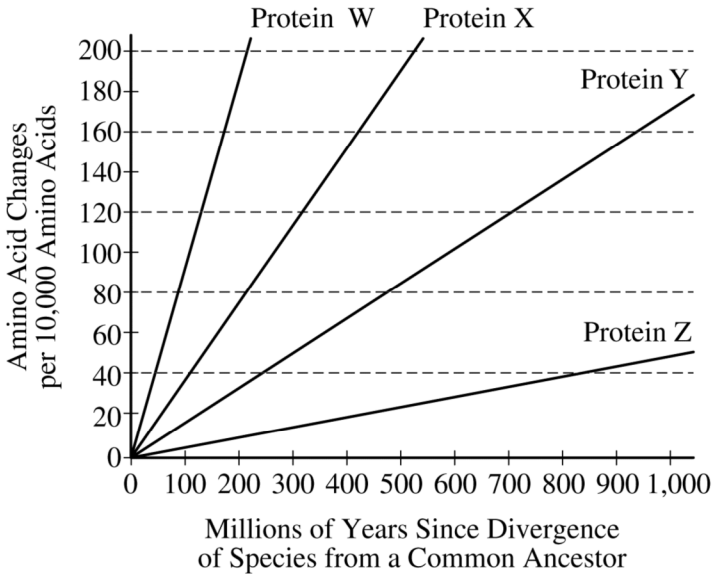
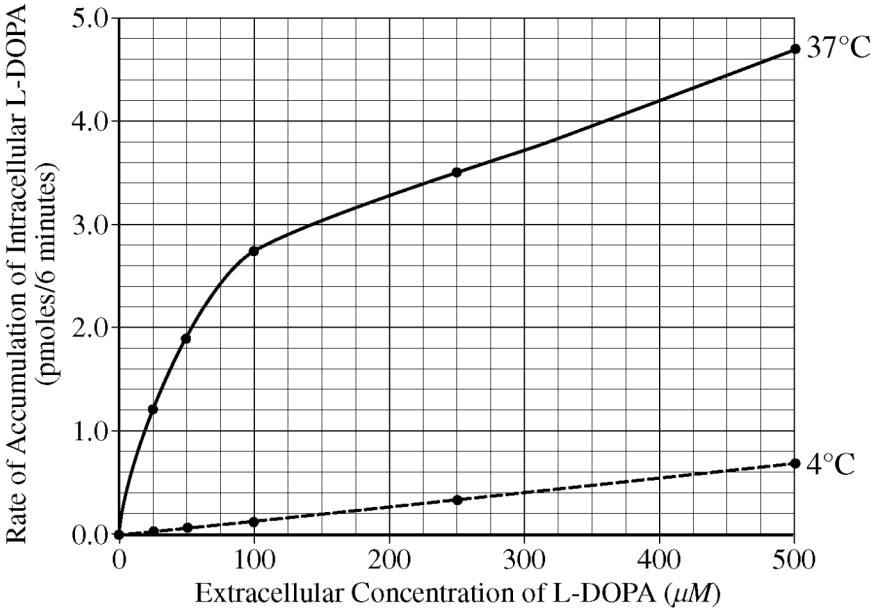


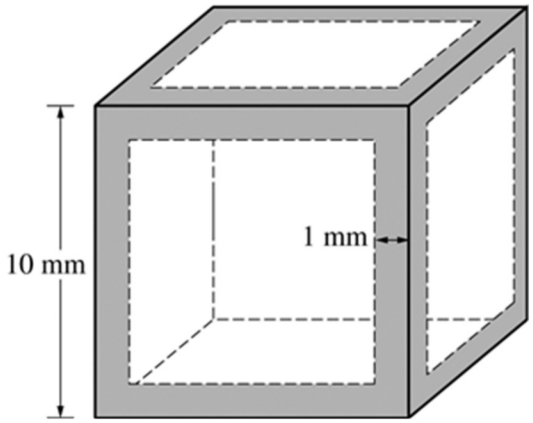
Figure 1. The rate of amino acid sequence divergence of proteins

123. Based on the data in Figure 1, calculate the rate of change in the amino acid sequence of the most highly conserved protein among the four proteins shown. Record your answer as the number of amino acid changes per 10,000 amino acids per 1 million years. Give your answer to the nearest hundredth.

124. Cultured hamster cells were incubated in the presence of different concentrations of extracellular L-DOPA, an organic compound that plays a role in regulating cellular functions. After 6 minutes, the amounts of L-DOPA that had accumulated inside the cells were determined. The rate of accumulation of intracellular L-DOPA was measured at two different temperatures, and the results are provided in the graph below.



According to the information in the graph, when the extracellular concentration of L-DOPA was 300 μM, how many times faster was the rate of L-DOPA accumulation at 37ºC compared to the rate at 4ºC? Give your answer to one decimal place.



125. The diagram above represents the outline of a potato cube that has been completely submerged in a purple dye overnight. The purple dye has penetrated 1 mm on each side, as indicated by the shading in the diagram.

Calculate the volume of the unpenetrated portion of the cube. Give your answer in cubic millimeters to the nearest whole number.

GO ON TO THE NEXT PAGE.

END OF SECTION I

IF YOU FINISH BEFORE TIME IS CALLED,
YOU MAY CHECK YOUR WORK ON THIS SECTION.

DO NOT GO ON TO SECTION II UNTIL YOU ARE TOLD TO DO SO.

MAKE SURE YOU HAVE DONE THE FOLLOWING.

- **PLACED YOUR AP NUMBER LABEL ON YOUR ANSWER SHEET**
- **WRITTEN AND GRIDDED YOUR AP NUMBER CORRECTLY ON YOUR ANSWER SHEET**
- **TAKEN THE AP EXAM LABEL FROM THE FRONT OF THIS BOOKLET AND PLACED IT ON YOUR ANSWER SHEET**

Section II: Free-Response Questions

This is the free-response section of the 2018 AP Exam.
It includes cover material and other administrative instructions
to help familiarize students with the mechanics of the exam.
(Note that future exams may differ in look from the following content.)

AP® Biology Exam

SECTION II: Free Response

2018

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
1 hour and 30 minutes
Number of Questions
8
Percent of Total Score
50%
Writing Instrument
Pen with black or dark blue ink
Electronic Device
Calculator allowed

Reading Period

Time
10 minutes. Use this time to read the questions and plan your answers. You may begin writing your responses before the reading period is over.

Writing Period

Time
1 hour and 20 minutes
Suggested Time
Approximately 22 minutes per long question, and 6 minutes per short question.
Weight
Approximate weights
Questions 1 and 2: 25% each
Questions 3—5: 10% each
Questions 6—8: 7% each

IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐
   First letter of your first name ☐
2. Date of birth
   ☐☐ Month ☐☐ Day ☐☐☐☐ Year
3. Six-digit school code
   ☐☐☐☐☐☐
4. Unless I check the box below, I grant the College Board the unlimited right to use, reproduce, and publish my free-response materials, both written and oral, for educational research and instructional purposes. My name and the name of my school will not be used in any way in connection with my free-response materials. I understand that I am free to mark "No" with no effect on my score or its reporting.
   No, I do not grant the College Board these rights. ☐

Instructions

The questions for Section II are printed in this booklet. You may use the unlined pages to organize your answers and for scratch work, but you must write your answers on the labeled pages provided for each question.

The proctor will announce the beginning and end of the reading period. You are advised to spend the 10-minute period reading all the questions, and to use the unlined pages to sketch graphs, make notes, and plan your answers. The focus of the reading period should be the organization of questions 1 and 2. You may begin writing your responses before the reading period is over.

Each answer should be written in paragraph form; an outline or bulleted list alone is not acceptable. Do not spend time restating the questions or providing more than the number of examples called for. For instance, if a question calls for two examples, you can earn credit only for the first two examples that you provide. Labeled diagrams may be used to supplement discussion, but unless specifically called for by the question, a diagram alone will not receive credit. Write clearly and legibly. Begin each answer on a new page. Do not skip lines. Cross out any errors you make; crossed-out work will not be scored.

Manage your time carefully. You may proceed freely from one question to the next. You may review your responses if you finish before the end of the exam is announced.

Form I
Form Code 4OBP4-S

AP® BIOLOGY EQUATIONS AND FORMULAS

Statistical Analysis and Probability

Mean

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Standard Deviation

$$s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$$

Standard Error of the Mean

$$SE_{\bar{x}} = \frac{s}{\sqrt{n}}$$

Chi-Square

$$\chi^2 = \sum \frac{(o-e)^2}{e}$$

Chi-Square Table

p value	Degrees of Freedom							
	1	2	3	4	5	6	7	8
0.05	3.84	5.99	7.82	9.49	11.07	12.59	14.07	15.51
0.01	6.64	9.21	11.34	13.28	15.09	16.81	18.48	20.09

$\bar{x}$ = sample mean

n = size of the sample

s = sample standard deviation (i.e., the sample-based estimate of the standard deviation of the population)

o = observed results

e = expected results

Degrees of freedom are equal to the number of distinct possible outcomes minus one.

Laws of Probability

If A and B are mutually exclusive, then:

$$P(\text{A or B}) = P(\text{A}) + P(\text{B})$$

If A and B are independent, then:

$$P(\text{A and B}) = P(\text{A}) \times P(\text{B})$$

Hardy-Weinberg Equations

$p^2 + 2pq + q^2 = 1$

$p + q = 1$

p = frequency of the dominant allele in a population

q = frequency of the recessive allele in a population

Metric Prefixes

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

Mode = value that occurs most frequently in a data set

Median = middle value that separates the greater and lesser halves of a data set

Mean = sum of all data points divided by number of data points

Range = value obtained by subtracting the smallest observation (sample minimum) from the greatest (sample maximum)

Rate and Growth

Rate

$$\frac{dY}{dt}$$

Population Growth

$$\frac{dN}{dt} = B - D$$

Exponential Growth

$$\frac{dN}{dt} = r_{max}N$$

Logistic Growth

$$\frac{dN}{dt} = r_{max}N\left(\frac{K-N}{K}\right)$$

Temperature Coefficient Q_{10}

$$Q_{10} = \left(\frac{k_2}{k_1}\right)^{\frac{10}{T_2 - T_1}}$$

Primary Productivity Calculation

$$\frac{\text{mg O}_2}{\text{L}} \times \frac{0.698 \text{ mL}}{\text{mg}} = \frac{\text{mL O}_2}{\text{L}}$$

$$\frac{\text{mL O}_2}{\text{L}} \times \frac{0.536 \text{ mg C fixed}}{\text{mL O}_2} = \frac{\text{mg C fixed}}{\text{L}}$$

(at standard temperature and pressure)

dY = amount of change

dt = change in time

B = birth rate

D = death rate

N = population size

K = carrying capacity

r_{max} = maximum per capita growth rate of population

T_2 = higher temperature

T_1 = lower temperature

k_2 = reaction rate at T_2

k_1 = reaction rate at T_1

Q_{10} = the factor by which the reaction rate increases when the temperature is raised by ten degrees

Water Potential (Ψ)

$\Psi = \Psi_P + \Psi_S$

Ψ_P = pressure potential

Ψ_S = solute potential

The water potential will be equal to the solute potential of a solution in an open container because the pressure potential of the solution in an open container is zero.

The Solute Potential of a Solution

$\Psi_S = -iCRT$

i = ionization constant (this is 1.0 for sucrose because sucrose does not ionize in water)

C = molar concentration

R = pressure constant (R = 0.0831 liter bars/mole K)

T = temperature in Kelvin (°C + 273)

Surface Area and Volume

Volume of a Sphere

$$V = \frac{4}{3}\pi r^3$$

Volume of a Rectangular Solid

$$V = \ell wh$$

Volume of a Right Cylinder

$$V = \pi r^2 h$$

Surface Area of a Sphere

$$A = 4\pi r^2$$

Surface Area of a Cube

$$A = 6s^2$$

Surface Area of a Rectangular Solid

$A = \Sigma$ surface area of each side

r = radius

ℓ = length

h = height

w = width

s = length of one side of a cube

A = surface area

V = volume

Σ = sum of all

Dilution (used to create a dilute solution from a concentrated stock solution)

$C_iV_i = C_fV_f$

i = initial (starting) C = concentration of solute

f = final (desired) V = volume of solution

Gibbs Free Energy

$\Delta G = \Delta H - T\Delta S$

ΔG = change in Gibbs free energy

ΔS = change in entropy

ΔH = change in enthalpy

T = absolute temperature (in Kelvin)

$pH = -\log_{10}[H^+]$

BIOLOGY

Section II

Total Time—1 hour and 30 minutes

Reading Period—10 minutes

Writing Period—1 hour and 20 minutes

8 Questions

Directions: Questions 1 and 2 are long free-response questions that require about 22 minutes each to answer and are worth 10 points each. Questions 3–8 are short free-response questions that require about 6 minutes each to answer. Questions 3–5 are worth 4 points each and questions 6–8 are worth 3 points each.

Read each question carefully and completely. You are advised to spend the 10-minute reading period planning your answers. You may begin writing your responses before the reading period is over. Write your response in the space provided for each question. Only material written in the space provided will be scored. Answers must be written out in paragraph form. Outlines, bulleted lists, or diagrams alone are not acceptable.

Question 1 is on the following page.

TABLE 1. SURVIVAL OF GENETICALLY MODIFIED *B. THAILANDENSIS* STRAINS

B. thailandensis Strain			Density of Live Cells (log CFU/mL)	
Culture	Protein S Produced	Protein R Produced	T=0 Hours	T=4 Hours
1	S1	none	7.3	4.5
2	S1	R1	7.9	7.9
3	S1	R2	6.5	3.8

1. In bacterial communities, where resources are often limited, survival requires the ability to sense, respond to, and cooperate or compete with neighboring organisms. In communities containing *Burkholderia thailandensis* bacteria, these abilities rely in part on contact-dependent communication with neighboring cells. This communication involves a signaling protein, protein S, that gets transported to the surface of the cell. When in direct physical contact with another bacterial cell, protein S is cleaved and internalized by the recipient cell, where it can act as a nuclease. There are different forms of protein S (e.g., S1, S2, S3) and different forms of an internal protein, protein R (e.g., R1, R2, R3). Recipient cells are protected from the nuclease activity of protein S if they produce the appropriate form of protein R.

   In an investigation, *B. thailandensis* strains were genetically engineered to produce different combinations of proteins S and R. The cells were placed in a nutrient-deficient medium (T=0 hours) and cultured for 4 hours (T=4 hours). The density of live cells in the culture was recorded at the two time points, T=0 hours and T=4 hours. The data are shown in Table 1.

   (a) **Construct** an appropriately labeled graph that represents the density of live cells in each culture of the three genetically altered *B. thailandensis* strains at both time points.

   (b) **Explain** the effect of expressing only S1 on the cells in culture 1. **Describe** the effect of expressing combinations of protein S and protein R on the survival of the cells in culture 2 AND culture 3.

   (c) In naturally occurring solid surface environments, such as soil, bacteria use this same signaling pathway to initiate formation of biofilms, which are densely populated aggregates of bacteria. In the center of the biofilm, cells are more likely to interact only with cells of the same bacterial strain. At the edges of the biofilm, cells are more likely to encounter cells of a different bacterial strain or species. **Identify** the most likely type of ecological relationships among cells in the center of the biofilm AND cells at the edges of the biofilm. **Provide reasoning** to support a researcher's claim that the bacteria cannot form biofilms at a low population density.

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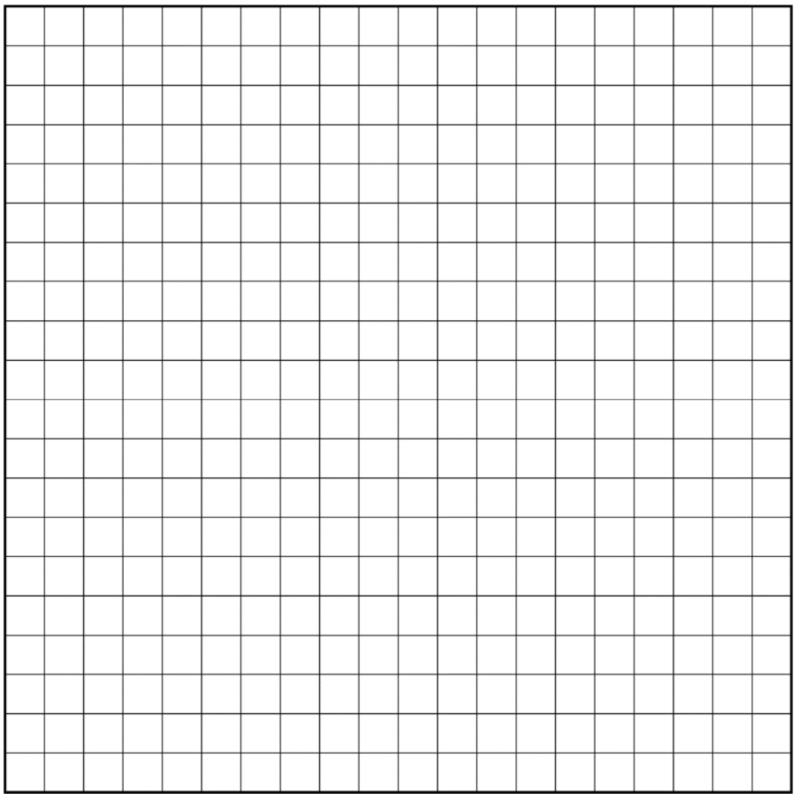
THIS PAGE MAY BE USED FOR TAKING NOTES AND PLANNING YOUR ANSWERS.
NOTES WRITTEN ON THIS PAGE WILL NOT BE SCORED.
WRITE ALL YOUR RESPONSES ON THE LINED PAGES.

PAGE FOR ANSWERING QUESTION 1



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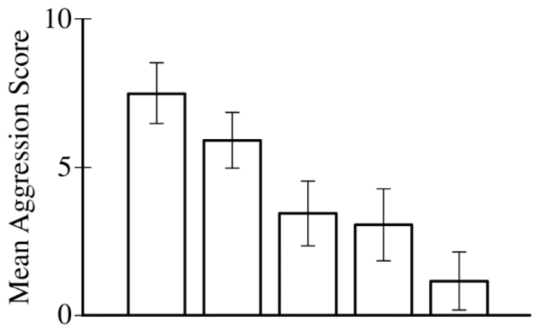

Treatment group	I	II	III	IV	V
Appearance of model	M	M	SA	SA	GW
Type of song	M	SA	M	SA	GW

M	Similar to males living on Makira Island
SA	Similar to males living on Santa Ana Island
GW	Similar to male golden whistlers

Figure 1. Behavioral responses of male flycatchers on Makira Island to different combinations of bird models and songs. The conditions of each treatment group are indicated below the graph. Error bars represent $\pm 2SE_{\bar{X}}$.

2. In an investigation about the roles of visual and auditory cues in mate competition, researchers studied two distinct populations of flycatchers (*Monarcha castaneiventris*), a species of bird that lives in the Solomon Islands. The flycatchers on Makira Island have light brown bellies, whereas those on Santa Ana Island are uniformly black. The songs produced by flycatchers of each population are also different from each other. To investigate male flycatcher competition, researchers exposed male flycatchers from Makira Island to different combinations of (1) bird models that resembled the males from each of the two populations, (2) recordings of the distinct songs produced by the members of each population, and (3) models and song recordings of a different bird species, golden whistlers *(Pachycephala pectoralis)*. On Makira Island, the researchers located territories defended by single mating pairs of flycatchers and assigned each territory to one of five treatment groups as indicated in Figure 1.

   For each trial, the researchers observed the behavioral response of the male flycatcher and assigned an aggression score from 0 to 10. A higher aggression score indicated a more aggressive behavioral response. The results of the study are represented in Figure 1.

   (a) Based on the information in Figure 1, **identify** ONE independent variable, ONE dependent variable, and ONE negative control treatment in the experimental design.

   (b) Based on the data in Figure 1, **make a claim** about the behavioral responses of the male Makira flycatchers to a model of a Makira flycatcher. Use the data to **justify** your claim. **Make a claim** about the behavioral responses of the male Makira flycatchers to the song recordings of a Makira flycatcher. Use the data to **justify** your claim.

   (c) A researcher claims that the Makira Island and the Santa Ana Island flycatchers are diverging into different species. **Identify** TWO potential prezygotic barriers that may be contributing to the divergence and speciation of these two populations of birds. **Identify** ONE piece of evidence that would indicate that speciation has already occurred within the flycatcher populations.

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THIS PAGE MAY BE USED FOR TAKING NOTES AND PLANNING YOUR ANSWERS.
NOTES WRITTEN ON THIS PAGE WILL NOT BE SCORED.
WRITE ALL YOUR RESPONSES ON THE LINED PAGES.

PAGE FOR ANSWERING QUESTION 2

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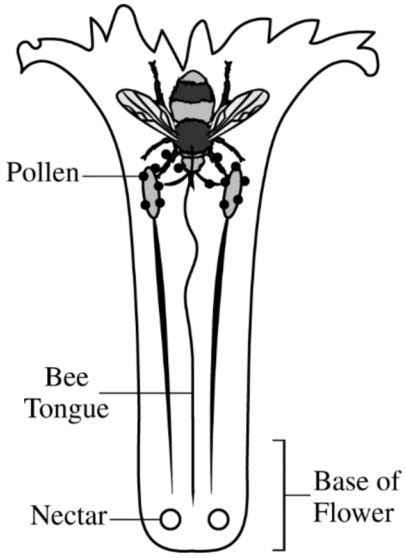

Figure 1. Bees access nectar from the base of a flower with their tongues and can transfer pollen from one flower to another.

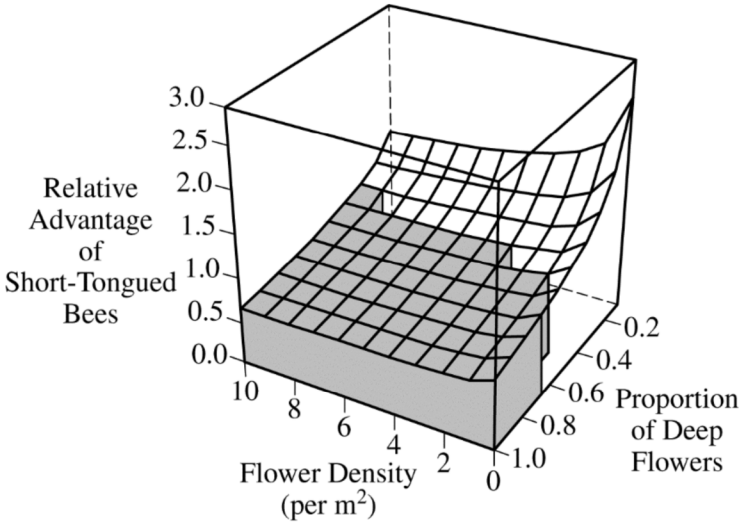

Figure 2. Relative advantage of short-tongued bees (y-axis) in relation to flower density (x-axis) and proportion of deep flowers (z-axis) is shown. White shading indicates conditions under which having a short tongue is an advantage. Gray shading indicates conditions under which having a short tongue is a disadvantage.

3. Bees use their tongues to access nectar as a food source from the base of flowers (Figure 1). Flowers vary in depth from shallow to deep, and bees vary in tongue length from short to long. Many species of plants depend on bees to transfer pollen from one flower to another for fertilization. Researchers constructed a graph to illustrate the conditions under which having a short tongue provides bees with an advantage in an environment where both short-tongued and long-tongued species of bees are present (Figure 2).

   (a) Based on the graph in Figure 2, **identify** the environmental conditions (flower density AND proportion of deep flowers) where a short-tongued bee has the greatest relative advantage over a long-tongued bee. Based on the graph in Figure 2, **identify** the range of proportion of deep flowers at which a long-tongued bee always has an advantage over a short-tongued bee.

   (b) Bees with short tongues are able to obtain nectar from deep flowers by drilling holes in the base of the flower without visiting the top of the flower. This behavior does not kill the flower. In a particular environment, bees with short tongues replace bees with long tongues. **Predict** the effect on the proportion of plants with deep flowers in future generations. **Justify** your prediction.

PAGE FOR ANSWERING QUESTION 3

ADDITIONAL PAGE FOR ANSWERING QUESTION 3

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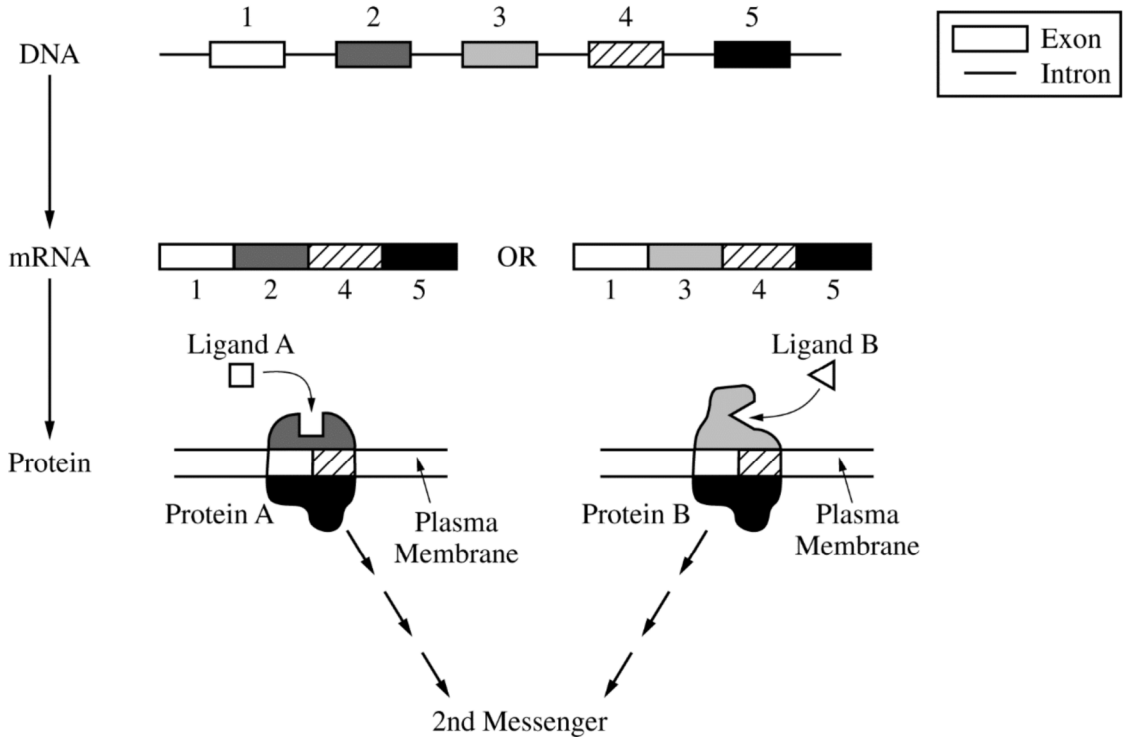

Figure 1. Receptor proteins produced as a result of alternative splicing followed by activation of a second messenger

4. Cell signaling in eukaryotes is often dependent on receptor proteins located in the plasma membrane. During the production of the mature mRNA molecules coding for these receptors, pre-mRNA molecules are processed to remove introns and to connect exons together. The exons contain the sequences that code for proteins. In certain instances, different mature mRNA molecules can be formed from the same pre-mRNA by alternative splicing, which results in different protein sequences in the resulting polypeptides. Figure 1 represents the expression of a gene with 5 exons that can be alternatively spliced to produce receptor protein A and receptor protein B.

   (a) **Explain** how ligand A and ligand B can cause identical cellular responses in a cell.

   (b) **Predict** the most likely effect of a two-nucleotide deletion in the middle of the intron located between exons 4 and 5 on the structure of protein A. **Justify** your prediction.

PAGE FOR ANSWERING QUESTION 4

ADDITIONAL PAGE FOR ANSWERING QUESTION 4

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5. Leptin is a hormone that signals an organism to suppress appetite. Leptin is released from fat cells in white adipose tissue and binds to receptors on cells in the hypothalamus, a region of the brain that controls appetite.

   (a) **Identify** the way that leptin produced by fat cells of adipose tissue in the abdomen can send a signal to the neuroendocrine cells in the hypothalamus.

   (b) Researchers are investigating the effectiveness of various treatments on three individuals with a history of increased appetite.

   - Individual I does not produce leptin but does have functional leptin receptors.
   - Individual II does produce leptin but does not have functional leptin receptors.
   - Individual III does not produce leptin and does not have functional leptin receptors.

   The first treatment involves injection of leptin into the blood. The second treatment involves gene therapy that results in the production of functional leptin receptors in cells of the hypothalamus. The third treatment combines both the injection of leptin and the leptin-receptor gene therapy. In the template provided, **draw** check marks in the appropriate boxes to indicate the individuals in which the treatment most likely results in appetite suppression. Columns and rows may have more than one check mark.

PAGE FOR ANSWERING QUESTION 5

	TREATMENT		
	Leptin Injection Only	Leptin Receptor Gene Therapy Only	Leptin Receptor Gene Therapy in Combination with Leptin Injection
Individual I			
Individual II			
Individual III			

ADDITIONAL PAGE FOR ANSWERING QUESTION 5

GO ON TO THE NEXT PAGE.

TABLE 1. NUCLEOTIDE PRESENT AT 6 DIFFERENT SNP POSITIONS IN INDIVIDUALS FROM 5 DIFFERENT HUMAN POPULATIONS

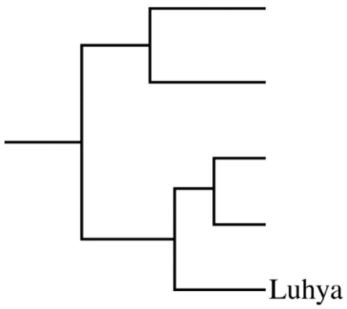
Population	SNP Position					
	1	2	3	4	5	6
Han	G	A	A	G	G	A
Yoruban	C	A	A	G	G	A
Luhya	G	A	A	A	G	A
Tibetan	C	T	T	A	C	A
Denisovan	C	T	T	A	C	T

6. The *EPAS1* gene in human populations encodes a transcription factor activated in low-oxygen conditions, such as those found in high altitude (mountainous) regions. Researchers collected DNA from several populations of modern humans, including Han, Yoruban, Luhya, and Tibetan. They also collected DNA from the fossils of Denisovans, a prehistoric population. The researchers sequenced the most common *EPAS1* allele in each population and determined the specific pattern of variations, called single nucleotide polymorphisms (SNPs), at six positions in each population (Table 1).

   (a) Use the template provided to **construct** a cladogram based on the *EPAS1* gene SNP sequences reported for each population. **Circle** the location on the cladogram that represents the most recent common ancestor of the populations shown in the table.

   (b) The *EPAS1* gene shows strong indications of positive selection in Tibetans, a population located in a mountainous region in Asia. **Describe** how the specific *EPAS1* gene SNP pattern shown above became common in the Tibetan population.

PAGE FOR ANSWERING QUESTION 6



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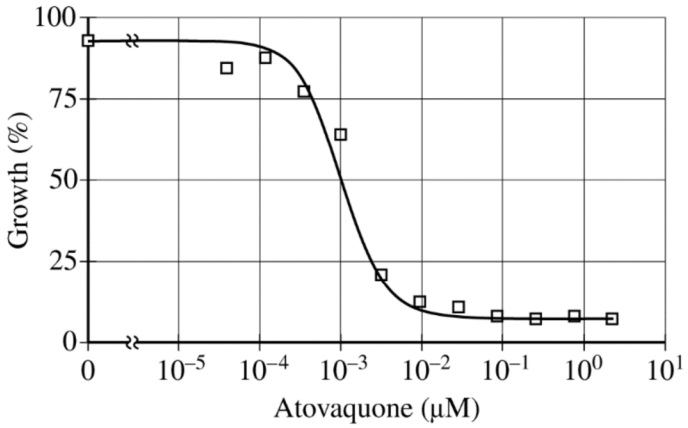

Figure 1. Effect of increasing concentrations of atovaquone on the growth of *P. falciparum*

7. Malaria is a human disease caused by the eukaryotic parasite *Plasmodium falciparum*. The enzyme dihydroorotate dehydrogenase (DHODH) is essential for the synthesis of pyrimidine bases, including thymine (T), cytosine (C), and uracil (U), in *P. falciparum*. To synthesize these bases, DHODH requires electrons that are donated by the electron transport chain protein cytochrome *b*. Atovaquone is a drug that irreversibly binds to cytochrome *b* and inhibits the growth of *P. falciparum (*Figure 1).

   (a) Based on an analysis of the data, **estimate** the effective dose of atovaquone that causes a fifty percent reduction in growth of *P. falciparum*.

   (b) Based on the information, **describe** how atovaquone most likely suppresses growth of *P. falciparum*.

   (c) **Identify** the cellular location where cytochrome *b*is most likely found.

PAGE FOR ANSWERING QUESTION 7

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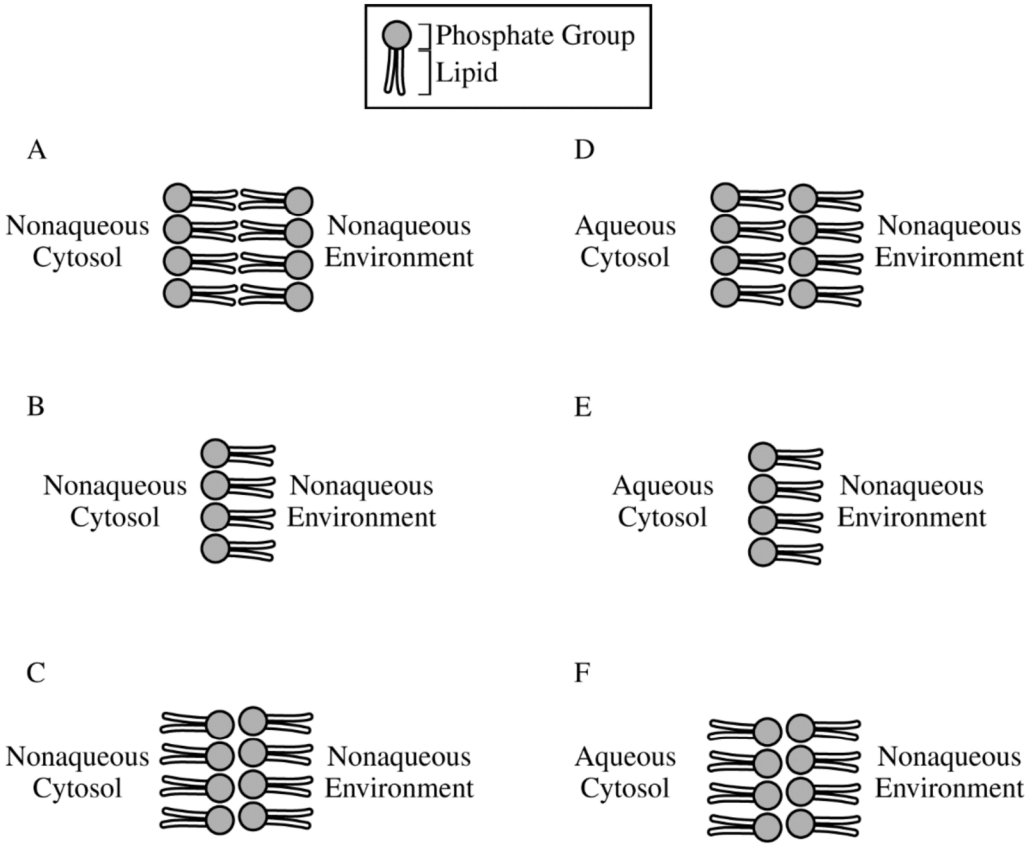

Figure 1. Proposed models of hypothetical plasma membranes. Each model represents a small portion of the hypothetical plasma membrane and illustrates the orientation of the phospholipids.

8. A student proposes six models of a hypothetical plasma membrane (Figure 1). **Identify** the model that best represents the plasma membrane of a hypothetical cell that exists in a nonaqueous environment and whose cytosol is similar to that of an animal cell. **Provide TWO pieces of reasoning** to support your identification.

PAGE FOR ANSWERING QUESTION 8

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ADDITIONAL PAGE FOR ANSWERING QUESTION 8

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STOP

END OF EXAM

IF YOU FINISH BEFORE TIME IS CALLED,
YOU MAY CHECK YOUR WORK ON THIS SECTION.

THE FOLLOWING INSTRUCTIONS APPLY TO THE COVERS OF THE SECTION II BOOKLET.

- **MAKE SURE YOU HAVE COMPLETED THE IDENTIFICATION INFORMATION AS REQUESTED ON THE FRONT AND BACK COVERS OF THE SECTION II BOOKLET.**

- **CHECK TO SEE THAT YOUR AP NUMBER LABEL APPEARS IN THE BOX ON THE FRONT COVER.**

- **MAKE SURE YOU HAVE USED THE SAME SET OF AP NUMBER LABELS ON ALL AP EXAMS YOU HAVE TAKEN THIS YEAR.**

Multiple-Choice and Grid-In Answer Key

The following contains the answers to
the multiple-choice and grid-in questions in this exam.

Answer Key for AP Biology
Practice Exam, Section I

Question 1: D
Question 2: D
Question 3: B
Question 4: D
Question 5: A
Question 6: B
Question 7: C
Question 8: A
Question 9: D
Question 10: C
Question 11: B
Question 12: A
Question 13: C
Question 14: A
Question 15: B
Question 16: D
Question 17: A
Question 18: A
Question 19: C
Question 20: C
Question 21: A
Question 22: D
Question 23: C
Question 24: B
Question 25: B
Question 26: C
Question 27: B
Question 28: D
Question 29: C
Question 30: B
Question 31: C
Question 32: C
Question 33: D
Question 34: B
Question 35: C
Question 36: A
Question 37: D
Question 38: A
Question 39: C
Question 40: B
Question 41: A
Question 42: B
Question 43: C
Question 44: A
Question 45: C
Question 46: D
Question 47: A
Question 48: B
Question 49: B
Question 50: D
Question 51: D
Question 52: C
Question 53: A

Question 121: .25, 1/4
Question 122: 427 through 430
Question 123: .04 through .05, 4/100 through 5/100
Question 124: 9.1 through 9.4, 91/10 through 94/10
Question 125: 512

Free-Response Scoring Guidelines

The following contains the scoring guidelines
for the free-response questions in this exam.

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Question 1

TABLE 1. SURVIVAL OF GENETICALLY MODIFIED *B. THAILANDENSIS* STRAINS

B. thailandensis Strain			Density of Live Cells (log CFU/mL)	
Culture	Protein S Produced	Protein R Produced	T=0 Hours	T=4 Hours
1	S1	none	7.3	4.5
2	S1	R1	7.9	7.9
3	S1	R2	6.5	3.8

In bacterial communities, where resources are often limited, survival requires the ability to sense, respond to, and cooperate or compete with neighboring organisms. In communities containing *Burkholderia thailandensis* bacteria, these abilities rely in part on contact-dependent communication with neighboring cells. This communication involves a signaling protein, protein S, that gets transported to the surface of the cell. When in direct physical contact with another bacterial cell, protein S is cleaved and internalized by the recipient cell, where it can act as a nuclease. There are different forms of protein S (e.g., S1, S2, S3) and different forms of an internal protein, protein R (e.g., R1, R2, R3). Recipient cells are protected from the nuclease activity of protein S if they produce the appropriate form of protein R.

In an investigation, *B. thailandensis* strains were genetically engineered to produce different combinations of proteins S and R. The cells were placed in a nutrient-deficient medium (T=0 hours) and cultured for 4 hours (T=4 hours). The density of live cells in the culture was recorded at the two time points, T=0 hours and T=4 hours. The data are shown in Table 1.

(a) **Construct** an appropriately labeled graph that represents the density of live cells in each culture of the three genetically altered *B. thailandensis* strains at both time points.

Construction (3 points)

- Plotted points on (modified) bar graph
- Labeled axes with cultures and times identified
- Units and scaling

(b) **Explain** the effect of expressing only S1 on the cells in culture 1. **Describe** the effect of expressing combinations of protein S and protein R on the survival of the cells in culture 2 AND culture 3.

Explanation (2 points)

- Cells expressing only S1 do not survive.
- Cells do not have an R protein OR have no protection (from nuclease activity).

Description (2 points)

- Culture 2/Cells with S1 and R1 survive.
- Culture 3/Cells with S1 and R2 do not survive.

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Question 1 (continued)

(c) In naturally occurring solid surface environments, such as soil, bacteria use this same signaling pathway to initiate formation of biofilms, which are densely populated aggregates of bacteria. In the center of the biofilm, cells are more likely to interact only with cells of the same bacterial strain. At the edges of the biofilm, cells are more likely to encounter cells of a different bacterial strain or species. **Identify** the most likely type of ecological relationships among cells in the center of the biofilm AND cells at the edges of the biofilm. **Provide reasoning** to support a researcher's claim that the bacteria cannot form biofilms at a low population density.

Identification (2 points)

Location	Interaction
Center	Cooperation
Edges	Competition OR predation

Reasoning (1 point)

- At low density cells are unlikely to come in contact with one another.
- At high density cells are more likely to come in contact with one another.
- At low densities cells do not produce enough signal/signaling molecule.

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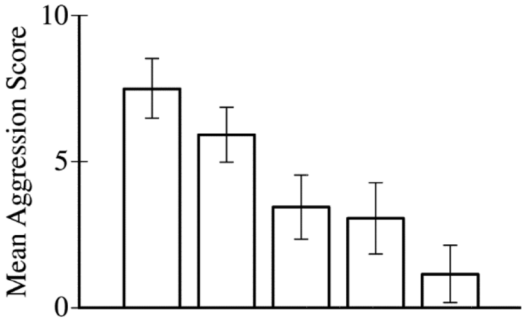
Question 2



Treatment group	I	II	III	IV	V
Appearance of model	M	M	SA	SA	GW
Type of song	M	SA	M	SA	GW

M	Similar to males living on Makira Island
SA	Similar to males living on Santa Ana Island
GW	Similar to male golden whistlers

Figure 1. Behavioral responses of male flycatchers on Makira Island to different combinations of bird models and songs. The conditions of each treatment group are indicated below the graph. Error bars represent $\pm 2SE_{\bar{x}}$.

In an investigation about the roles of visual and auditory cues in mate competition, researchers studied two distinct populations of flycatchers (*Monarcha castaneiventris*), a species of bird that lives in the Solomon Islands. The flycatchers on Makira Island have light brown bellies, whereas those on Santa Ana Island are uniformly black. The songs produced by flycatchers of each population are also different from each other. To investigate male flycatcher competition, researchers exposed male flycatchers from Makira Island to different combinations of (1) bird models that resembled the males from each of the two populations, (2) recordings of the distinct songs produced by the members of each population, and (3) models and song recordings of a different bird species, golden whistlers *(Pachycephala pectoralis*). On Makira Island, the researchers located territories defended by single mating pairs of flycatchers and assigned each territory to one of five treatment groups as indicated in Figure 1.

For each trial, the researchers observed the behavioral response of the male flycatcher and assigned an aggression score from 0 to 10. A higher aggression score indicated a more aggressive behavioral response. The results of the study are represented in Figure 1.

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Question 2 (continued)

(a) Based on the information in Figure 1, **identify** ONE independent variable, ONE dependent variable, and ONE negative control treatment in the experimental design.

Identification (1 point each; 3 points maximum)
- Independent Variable: song OR model OR the combinations of song and model/treatment groups
- Dependent Variable: aggression score/behavioral response
- Negative Control: Golden whistler (GW)/Group V

(b) Based on the data in Figure 1, **make a claim** about the behavioral responses of the male Makira flycatchers to a model of a Makira flycatcher. Use the data to **justify** your claim. **Make a claim** about the behavioral responses of the male Makira flycatchers to the song recordings of a Makira flycatcher. Use the data to **justify** your claim.

Claim (2 points)	Justification (2 points; 1 point maximum per box)
Males respond aggressively to visual cues of members of the same population.	• Treatment I is greater than treatment III. • Treatment II is greater than treatment IV. • Treatments I and II are greater than treatments III and IV.
Males do not respond aggressively to audio cues.	• Treatment I is the same as treatment II. • Treatment III is the same as treatment IV.

(c) A researcher claims that the Makira Island and the Santa Ana Island flycatchers are diverging into different species. **Identify** TWO potential prezygotic barriers that may be contributing to the divergence and speciation of these two populations of birds. **Identify** ONE piece of evidence that would indicate that speciation has already occurred within the flycatcher populations.

Identification of prezygotic barrier (2 points maximum)
- Geographic barrier
- Behavioral barrier
- Physical OR mechanical barrier
- Temporal barrier
- Ecological barrier

Identification of evidence (1 point maximum)
- Makira males do not recognize/respond aggressively to Santa Ana males as reproductive competitors/mate competition
- Reproductive isolation based on the inability to mate OR recognize potential mates
- Reproductive isolation based on the production of nonviable OR infertile offspring
- Differences in DNA OR protein/amino acid sequences

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Question 3

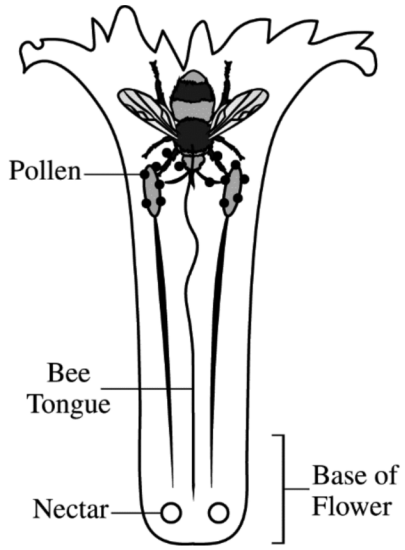

Figure 1. Bees access nectar from the base of a flower with their tongues and can transfer pollen from one flower to another.

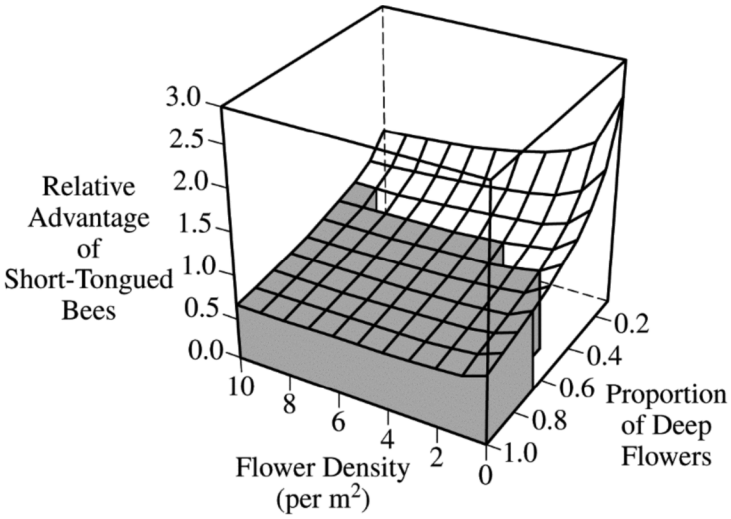

Figure 2. Relative advantage of short-tongued bees (*y*-axis) in relation to flower density (*x*-axis) and proportion of deep flowers (*z*-axis) is shown. White shading indicates conditions under which having a short tongue is an advantage. Gray shading indicates conditions under which having a short tongue is a disadvantage.

Bees use their tongues to access nectar as a food source from the base of flowers (Figure 1). Flowers vary in depth from shallow to deep, and bees vary in tongue length from short to long. Many species of plants depend on bees to transfer pollen from one flower to another for fertilization. Researchers constructed a graph to illustrate the conditions under which having a short tongue provides bees with an advantage in an environment where both short-tongued and long-tongued species of bees are present (Figure 2).

(a) Based on the graph in Figure 2, **identify** the environmental conditions (flower density AND proportion of deep flowers) where a short-tongued bee has the greatest relative advantage over a long-tongued bee. Based on the graph in Figure 2, **identify** the range of proportion of deep flowers at which a long-tongued bee always has an advantage over a short-tongued bee.

Identification (short-tongued advantage) (1 point)

- Low density of flowers AND low proportion of deep flowers/high proportion of shallow flowers
- Range or point within the area of the graph less than or equal to 4 (flower density) AND less than or equal to 0.4 (proportion)

Identification (long-tongued advantage) (1 point)

- Minimum value greater than or equal to 0.60

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Question 3 (continued)

(b) Bees with short tongues are able to obtain nectar from deep flowers by drilling holes in the base of the flower without visiting the top of the flower. This behavior does not kill the flower. In a particular environment, bees with short tongues replace bees with long tongues. **Predict** the effect on the proportion of plants with deep flowers in future generations. **Justify** your prediction.

Prediction (1 point)
- The proportion of plants with deep flowers will decrease.

Justification (1 point)
- The bees will not transfer pollen from the deep flowers.
- Seed production from deep flowers decreases.
- Plants with deep flowers will not be fertilized/pollinated/able to reproduce.
- Bees can obtain nectar without touching the pollen.
- Short flowers will be selected for/deep flowers will be selected against.

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Question 4

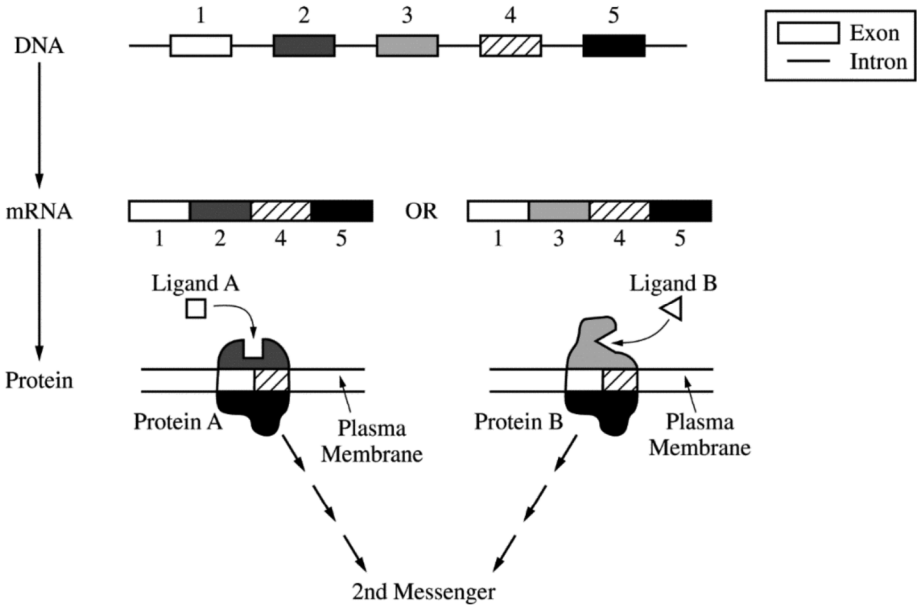

Figure 1. Receptor proteins produced as a result of alternative splicing followed by activation of a second messenger

Cell signaling in eukaryotes is often dependent on receptor proteins located in the plasma membrane. During the production of the mature mRNA molecules coding for these receptors, pre-mRNA molecules are processed to remove introns and to connect exons together. The exons contain the sequences that code for proteins. In certain instances, different mature mRNA molecules can be formed from the same pre-mRNA by alternative splicing, which results in different protein sequences in the resulting polypeptides. Figure 1 represents the expression of a gene with 5 exons that can be alternatively spliced to produce receptor protein A and receptor protein B.

(a) **Explain** how ligand A and ligand B can cause identical cellular responses in a cell.

Explanation (2 points)

- Protein A and Protein B have the same intracellular domain/section 5 is the same.
- Protein A and Protein B activate the same signal transduction pathway/second messenger.

(b) **Predict** the most likely effect of a two-nucleotide deletion in the middle of the intron located between exons 4 and 5 on the structure of protein A. **Justify** your prediction.

Prediction (1 point)

- No change

Justification (1 point)

- The intron is removed.
- The intron does not contain protein-coding information.
- The intron is not translated.

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Question 5

Leptin is a hormone that signals an organism to suppress appetite. Leptin is released from fat cells in white adipose tissue and binds to receptors on cells in the hypothalamus, a region of the brain that controls appetite.

(a) **Identify** the way that leptin produced by fat cells of adipose tissue in the abdomen can send a signal to the neuroendocrine cells in the hypothalamus.

Identification (1 point)

- The leptin molecule travels through the blood OR circulatory system.

(b) Researchers are investigating the effectiveness of various treatments on three individuals with a history of increased appetite.

- Individual I does not produce leptin but does have functional leptin receptors.
- Individual II does produce leptin but does not have functional leptin receptors.
- Individual III does not produce leptin and does not have functional leptin receptors.

The first treatment involves injection of leptin into the blood. The second treatment involves gene therapy that results in the production of functional leptin receptors in cells of the hypothalamus. The third treatment combines both the injection of leptin and the leptin-receptor gene therapy. In the template provided, **draw** check marks in the appropriate boxes to indicate the individuals in which the treatment most likely results in appetite suppression. Columns and rows may have more than one check mark.

Draw check marks (3 points, 1 point per column)

TREATMENT

	Leptin Injection Only	Leptin Receptor Gene Therapy Only	Leptin Receptor Gene Therapy in Combination with Leptin Injection
Individual I	✓		✓
Individual II		✓	✓
Individual III			✓

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Question 6

TABLE 1. NUCLEOTIDE PRESENT AT 6 DIFFERENT SNP POSITIONS IN INDIVIDUALS FROM 5 DIFFERENT HUMAN POPULATIONS

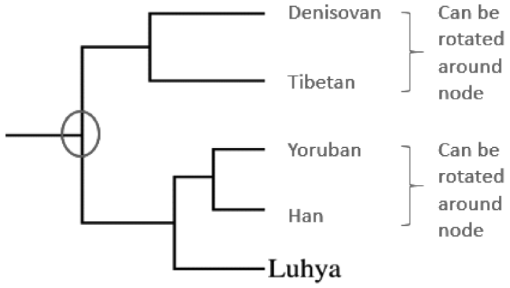
Population	SNP Position					
	1	2	3	4	5	6
Han	G	A	A	G	G	A
Yoruban	C	A	A	G	G	A
Luhya	G	A	A	A	G	A
Tibetan	C	T	T	A	C	A
Denisovan	C	T	T	A	C	T

The *EPAS1* gene in human populations encodes a transcription factor activated in low-oxygen conditions, such as those found in high altitude (mountainous) regions. Researchers collected DNA from several populations of modern humans, including Han, Yoruban, Luhya, and Tibetan. They also collected DNA from the fossils of Denisovans, a prehistoric population. The researchers sequenced the most common *EPAS1* allele in each population and determined the specific pattern of variations, called single nucleotide polymorphisms (SNPs), at six positions in each population (Table 1).

(a) Use the template provided to **construct** a cladogram based on the *EPAS1* gene SNP sequences reported for each population. **Circle** the location on the cladogram that represents the most recent common ancestor of the populations shown in the table.

Construction (1 point)

Circle (1 point)



(b) The *EPAS1* gene shows strong indications of positive selection in Tibetans, a population located in a mountainous region in Asia. **Describe** how the specific *EPAS1* gene SNP pattern shown above became common in the Tibetan population.

Description (1 point)

- Natural selection for individuals with this specific SNP variation/allele

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Question 7

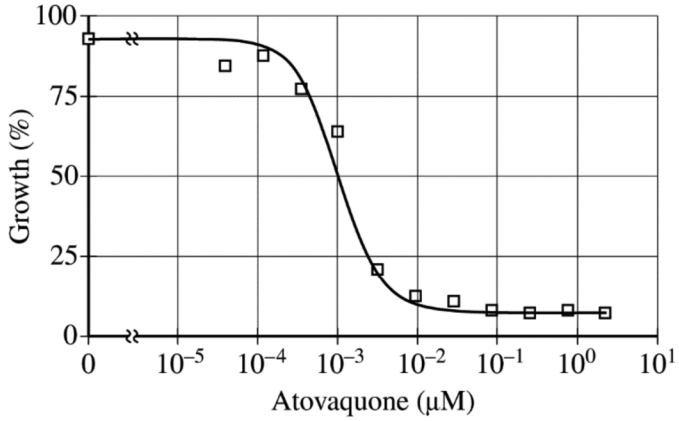

Figure 1. Effect of increasing concentrations of atovaquone on the growth of *P. falciparum*

Malaria is a human disease caused by the eukaryotic parasite *Plasmodium falciparum*. The enzyme dihydroorotate dehydrogenase (DHODH) is essential for the synthesis of pyrimidine bases, including thymine (T), cytosine (C), and uracil (U), in *P. falciparum*. To synthesize these bases, DHODH requires electrons that are donated by the electron transport chain protein cytochrome *b*. Atovaquone is a drug that irreversibly binds to cytochrome *b* and inhibits the growth of *P. falciparum* (Figure 1).

(a) Based on an analysis of the data, **estimate** the effective dose of atovaquone that causes a fifty percent reduction in growth of *P. falciparum*.

Estimation (1 point)

- 10^{-3} μM to $10^{-2.5}$ μM
- 0.001 μM to 0.003 μM

(b) Based on the information, **describe** how atovaquone most likely suppresses growth of *P. falciparum*.

Description (1 point)

- Atovaquone prevents/reduces function of the electron transport chain
- Atovaquone prevents/reduces donation of electrons
- Atovaquone prevents/reduces synthesis of pyrimidine bases
- Atovaquone prevents/reduces DNA replication OR transcription

(b) **Identify** the cellular location where cytochrome *b* is most likely found.

Identification (1 point)

- Mitochondria

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Question 8

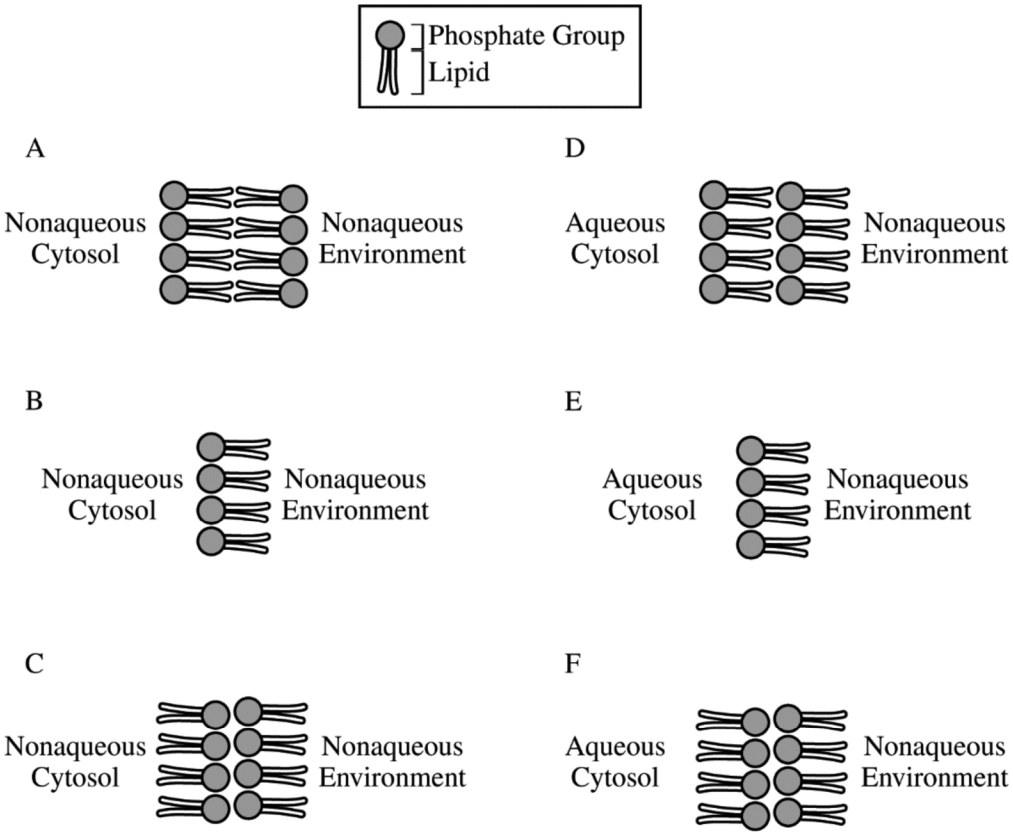

Figure 1. Proposed models of hypothetical plasma membranes. Each model represents a small portion of the hypothetical plasma membrane and illustrates the orientation of the phospholipids.

A student proposes six models of a hypothetical plasma membrane (Figure 1). **Identify** the model that best represents the plasma membrane of a hypothetical cell that exists in a nonaqueous environment and whose cytosol is similar to that of an animal cell. **Provide TWO pieces of reasoning** to support your identification.

Identification (1 point)

- Model E

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Question 8 (continued)

Reasoning (2 points)

Reasoning to support the model (1 point maximum per row per model; points can only be earned if a (+) sign is present for that model)	**Model identified** + indicates a point is earned (–) indicates a point is not earned					
	A	B	C	D	E	F
AQUEOUS CYTOSOL • Cytosol is aqueous	–	–	–	+	+	+
ORIENTATION OF LIPIDS AND PHOSPHOLIPID HEADS • Phospholipid heads orient towards aqueous environment AND hydrophobic tails orient towards nonaqueous environment	–	–	–	–	+	–
PHOSPHOLIPID HEAD LOCATION • Phospholipid heads (repel one another and) cannot be found in the interior of the bilayer *N/A: The characteristic does not apply to a monolayer*	+	N/A	–	–	N/A	–
MAXIMUM NUMBER OF POINTS PER MODEL	1	0	0	1	2	1

Scoring Worksheet

The following provides a scoring worksheet and conversion table used for calculating a composite score of the exam.

2018 AP Biology Scoring Worksheet

Section I: Multiple Choice and Grid-In

_____	×	1.0344	=	_____
Number Correct (out of 58)				Weighted Section I Score (Do not round)

Section II: Free Response

Question 1	_____ (out of 10)	×	1.5000	=	_____ (Do not round)
Question 2	_____ (out of 10)	×	1.5000	=	_____ (Do not round)
Question 3	_____ (out of 4)	×	1.4285	=	_____ (Do not round)
Question 4	_____ (out of 4)	×	1.4285	=	_____ (Do not round)
Question 5	_____ (out of 4)	×	1.4285	=	_____ (Do not round)
Question 6	_____ (out of 3)	×	1.4285	=	_____ (Do not round)
Question 7	_____ (out of 3)	×	1.4285	=	_____ (Do not round)
Question 8	_____ (out of 3)	×	1.4285	=	_____ (Do not round)

Sum = _____
Weighted Section II Score (Do not round)

Composite Score

_____	+	_____	=	_____
Weighted Section I Score		Weighted Section II Score		Composite Score (Round to nearest whole number)

AP Score Conversion Chart
Biology

Composite Score Range	AP Score
96-120	5
79-95	4
58-78	3
33-57	2
0-32	1

Question Descriptors and Performance Data

The following contains tables showing the content assessed,
the correct answer, and how AP students performed on each question.

2018 AP Biology
Question Descriptors and Performance Data

Multiple-Choice Questions

Question	Learning Objectives	Essential Knowledge	Science Practice	Key	% Correct
1	4.20	4B4	6.3	D	91
2	4.18	4B2	1.4	D	94
3	3.15	3A4	6.5	B	84
4	1.2	1A1	2.2	D	76
5	1.22	1C2	6.4	A	87
6	3.40	3E1	5.1	B	93
7	4.19	4B3	5.2	C	91
8	2.23	2D1	4.2	A	57
9	2.3	2A1	6.4	D	73
10	1.9	1A4	5.3	C	72
11	3.36	3D3	1.5	B	84
12	1.19	1B2	1.1	A	76
13	4.13	4A5	6.4	C	89
14	1.11	1A4	4.2	A	68
15	1.26	1C3	5.3	B	80
16	1.1	1A1	1.5|2.2	D	75
17	1.5	1A2	7.1	A	61
18	2.11	2B1	1.1	A	82
19	2.5	2A2	6.2	C	81
20	3.35	3D2	1.1	C	73
21	3.14	3A3	2.2	A	80
22	3.26	3C1	7.2	D	64
23	4.26	4C3	6.4	C	67
24	3.13	3A3	3.1	B	74
25	3.12	3A3	1.1|7.2	B	44
26	4.4	4A2	6.4	C	62
27	2.16	2C1	7.2	B	72
28	3.8|3.7	3A2	1.2|6.4	D	78
29	3.21	3B1	1.4	C	70
30	4.14	4A6	2.2	B	64
31	2.17	2C1	5.3	C	71
32	3.4	3A1	1.2	C	73
33	2.16	2C1	7.2	D	54
34	2.35	2E2	4.2	B	49
35	3.29	3C3	6.2	C	55
36	3.8	3A2	1.2	A	60
37	1.28	1D1	3.3	D	68
38	2.39	2E3	6.1	A	67
39	2.29	2D4	1.2	C	55

2018 AP Biology
Question Descriptors and Performance Data

Question	Learning Objectives	Essential Knowledge	Science Practice	Key	% Correct
40	2.18	2C1	6.4	B	75
41	3.39	3D4	6.2	A	44
42	3.34	3D2	6.2	B	60
43	3.28	3C2	6.2	C	49
44	4.26	4C3	6.4	A	66
45	2.22	2D1	1.3|3.2	C	78
46	4.19	4B3	5.2	D	73
47	4.11	4A5	1.4|4.1	A	40
48	1.5	1A2	7.1	B	60
49	3.18	3B1	7.1	B	76
50	3.26	3C1	7.2	D	54
51	2.14	2B3	1.4	D	62
52	2.10|2.10	2B1	1.4|3.1	C	66
53	2.9|2.16	2A3|2C1	1.1|1.4|7.2	A	37
121	3.14	3A3	2.2	.25, 1/4	83
122	1.6	1A3	1.4|2.1	427–430	51
123	1.26	1C3	5.3	.04–.05, 4/100 –5/100	47
124	2.24	2D1	5.1	9.1–9.4, 91/10 –94/10	41
125	2.6	2A3	2.2	512	43

Free-Response Questions

Question	Learning Objective	Essential Knowledge	Science Practice	Mean Score
1	2.24|3.34|4.13|4.19|4.19|4.23	2D1|3D2|4A5|4B3|4C2	5.1|6.2|6.4|2.2|5.2|6.2	4.19
2	1.23|1.22|2.22|2.22|2.23|2.23|3.40|3.42|4.11|4.11	1C2|2D1|3E1|4A5	4.1|6.4|1.3|3.2|4.2|7.2|5.1|7.1|1.4|4.1	4.70
3	1.5|2.24|4.13	1A2|2D1|4A5	7.1|5.1|6.4	1.89
4	3.6|3.33|3.36	3A1|3D1|3D3	6.4|1.4|1.5	0.99
5	3.35|4.9	3D2|4A4	1.1|6.4	2.19
6	1.5|1.19	1A2|1B2	7.1|1.1	1.74
7	2.28|3.3|3.8|4.6	2D3|3A1|3A2|4A2	1.4|1.2|1.2|1.4	1.46
8	2.11|2.11|2.11|2.12	2B1|2B2	1.1|7.1|7.2|1.4	0.72

AP Biology

The College Board

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