CollegeBoard

AP® Biology Practice Exam

From the 2014 Administration

NOTE: This is a modified version of the 2014 AP Biology Exam.

Contents

Note: This publication shows the page numbers that appeared in the *2013–14 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 *2013–14 AP Exam Instructions* book.

AP® Biology Exam

Regularly Scheduled Exam Date: Monday morning, May 12, 2014

Late-Testing Exam Date: Friday afternoon, May 23, 2014

Section I Total Time: 1 hr. 30 min. Section II Total Time: 1 hr. 30 min.

What Proctors Need to Bring to This Exam

- Exam packets
- Answer sheets
- AP Student Packs
- *2013-14 AP Coordinator's Manual*
- This book — *AP Exam Instructions*
- School Code and Home-School/Self-Study Codes
- Extra calculators
- Pencil sharpener
- 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 in the testing room"

SECTION I: Multiple Choice and Grid-In

Students are allowed to use four-function (with square root) calculators throughout the entire AP Biology Exam. Graphing calculators and scientific calculators are not permitted for use on the AP Biology Exam. See pages 42–45 of the *2013-14 AP Coordinator's Manual* for more information.

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 43 of the *2013-14 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.

If you are giving the regularly scheduled exam, say:

It is Monday morning, May 12, and you will be taking the AP Biology Exam.

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

It is Friday afternoon, May 23, and you will be taking the AP Biology Exam.

In a moment, you will open the packet that contains your exam materials. By opening this packet, you agree to all of the AP Program's policies and procedures outlined in the *2013-14 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. Now place it on page 1 of your answer sheet on the light blue box near the top right-hand 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 will be processed correctly.

Read the statements on the front cover of Section I and look up when you have finished. . . .

Sign your name and write today's date. Look up when you have finished. . . .

Now print your full legal name where indicated. Are there any questions? . . .

Turn to the back cover and read it completely. Look up when you have finished. . . .

Are there any questions? . . .

Section I is the multiple-choice and grid-in portion of the exam. Mark all of your responses beginning on page 2 of your answer sheet, one response per question. 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. Four-function calculators (with square root) are allowed.

The grid-in questions have no answer choices. You will solve each problem and write your final numeric answer in the boxes at the top of the grid and fill in the corresponding circles. 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 here _____. Note Stop Time here _____. 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 30 minutes, say:

Stop working. Close your booklet and put your answer sheet on your desk, face up. Make sure you have your AP number label and an AP Exam label on page 1 of your answer sheet. I will now collect your answer sheet.

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

Now you must seal your exam booklet. 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, face up. 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. Everything you placed under your chair at the beginning of the exam must stay there. Leave your shrinkwrapped Section II packet on your desk during the break. You are not allowed to consult teachers, other students, or textbooks about the exam 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 are not allowed to discuss the multiple-choice section of this exam. If you do not follow these rules, your score could 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 place an AP number label 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 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? . . .

I need to collect the Student Pack from anyone who will be taking another AP Exam. You may keep it only if you are not taking any other AP Exams this year. If you have no other AP Exams to take, place your Student Pack under your chair now. . . .

While Student Packs are being collected, 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? . . .

Section II begins with a 10-minute reading period. During the reading period, you will read the questions and plan your answers to the questions. You may use the unlined pages of this booklet to organize your answers and for scratch work, but you must write your answers on the lined pages provided for each question. Answers must be written in ink. Are there any questions? . . .

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

Note Start Time here _____. Note Stop Time here _____. Check that students are writing any notes in the appropriate areas in the Section II booklet. If any students begin writing their responses during this time, remind them that the reading period is not yet over, and that the reading period is designed to provide students with time to develop better organized, higher scoring responses. If the students choose to continue writing responses, take no further action. After 10 minutes, say:

Stop. The reading period is over. You have 1 hour and 20 minutes to answer the questions. You are responsible for pacing yourself, and may proceed freely from one question to the next. If you need more paper during the exam, raise your hand. At the top of each extra piece of paper you use, be sure to write only your AP number and the number of the question you are working on. Do not write your name. Are there any questions? . . .

You may begin.

Note Start Time here _____. Note Stop Time here _____. 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, face up.

If any students used extra paper for the free-response section, have those students staple the extra sheet/s to the first page corresponding to that question in their exam booklets. 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 his or her 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 these specific free-response questions with anyone unless they are released on the College Board website in about two days. Your AP score results will be available online in July.

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

None of the questions in this exam may ever be discussed or shared in any way at any time. Your AP 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.

All exam materials should be put in secure storage until they are returned to the AP Program after your school's last administration. 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 *2013-14 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 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.)

AP Answer Sheet 2014

AP Number Label
(from Student Pack)

B123456789T

AP Exam Label
(from Section I Booklet)

CollegeBoard

COMPLETE THIS AREA AT EVERY EXAM. **USE NO. 2 PENCIL ONLY**

To maintain the security of the exam and the validity of my AP score, I will allow no one else to see the multiple-choice questions. I will seal the multiple-choice booklet when asked to do so, and I will not discuss these questions with anyone at any time after completing the section. I am aware of and agree to the AP Program's policies and procedures as outlined in the *2013-14 Bulletin for AP Students and Parents*, including using testing accommodations (e.g., extended time, computer, etc.) only if I have been preapproved by College Board Services for Students with Disabilities.

A. SIGNATURE Sign your legal name as it will appear on your college applications. Date

B. LEGAL NAME Omit apostrophes, Jr., II.

Legal Last Name — First 15 Letters | Legal First Name — First 12 Letters | MI

C. YOUR AP NUMBER

D. EXAM DATE Month | Day

E. EXAM START TIME AM | PM

F. MULTIPLE-CHOICE BOOKLET SERIAL NUMBER S

G. ONLINE PROVIDER CODE

COMPLETE THIS AREA ONLY ONCE.

I. AREA CODE AND PHONE NUMBER

INTERNATIONAL PHONE

J. SCHOOL YOU ATTEND

SCHOOL CODE | School Name | City | State | Country

K. DATE OF BIRTH

Month: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec | Day | Year

L. SOCIAL SECURITY NUMBER (Optional)

M. COLLEGE TO RECEIVE YOUR AP SCORE REPORT

COLLEGE CODE

Using the college code listed in the AP Student Pack, indicate the **ONE** college that you want to receive your AP score report.

College Name | City | State | Country

N. CURRENT GRADE LEVEL

- Not yet in 9th grade
- 9th
- 10th
- 11th
- 12th
- No longer in high school

H. AP EXAM I AM TAKING USING THIS ANSWER SHEET Exam Name: | Form: | Form Code:

773898

SCHOOL USE ONLY

Section Number: 1 2 3 4 5 6 7 8 9

Fee Reduction Granted: 1 Option 1 2 Option 2

99735-00657 • UNLWEB114

Q3779/1-4

COMPLETE THIS AREA AT EACH EXAM (IF APPLICABLE)

O. SURVEY QUESTIONS — Answer the survey questions in the AP Student Pack. Do not put responses to exam questions in this section.

1 (A)(B)(C)(D)(E)(F)(G)(H)(I)	4 (A)(B)(C)(D)(E)(F)(G)(H)(I)	7 (A)(B)(C)(D)(E)(F)(G)(H)(I)
2 (A)(B)(C)(D)(E)(F)(G)(H)(I)	5 (A)(B)(C)(D)(E)(F)(G)(H)(I)	8 (A)(B)(C)(D)(E)(F)(G)(H)(I)
3 (A)(B)(C)(D)(E)(F)(G)(H)(I)	6 (A)(B)(C)(D)(E)(F)(G)(H)(I)	9 (A)(B)(C)(D)(E)(F)(G)(H)(I)

P. LANGUAGE — Do not complete this section unless instructed to do so.

If this answer sheet is for the French Language and Culture, German Language and Culture, Italian Language and Culture, Spanish Language and Culture, or Spanish Literature and Culture Exam, please answer the following questions. Your responses will not affect your score.

1. Have you lived or studied for one month or more in a country where the language of the exam you are now taking is spoken?

◯ Yes ◯ No

2. Do you regularly speak or hear the language at home?

◯ Yes ◯ No

QUESTIONS 1–75

Indicate your answers to the exam questions in this section (pages 2 and 3). Mark only one response per question. If a question has only four answer options, do not mark option E. Answers written in the multiple-choice booklet will not be scored.

COMPLETE MARK ● EXAMPLES OF INCOMPLETE MARKS 

You must use a No. 2 pencil and marks must be complete. Do not use a mechanical pencil. It is very important that you fill in the entire circle darkly and completely. If you change your response, erase as completely as possible. Incomplete marks or erasures may affect your score.

1 (A)(B)(C)(D)(E)	26 (A)(B)(C)(D)(E)	51 (A)(B)(C)(D)(E)
2 (A)(B)(C)(D)(E)	27 (A)(B)(C)(D)(E)	52 (A)(B)(C)(D)(E)
3 (A)(B)(C)(D)(E)	28 (A)(B)(C)(D)(E)	53 (A)(B)(C)(D)(E)
4 (A)(B)(C)(D)(E)	29 (A)(B)(C)(D)(E)	54 (A)(B)(C)(D)(E)
5 (A)(B)(C)(D)(E)	30 (A)(B)(C)(D)(E)	55 (A)(B)(C)(D)(E)
6 (A)(B)(C)(D)(E)	31 (A)(B)(C)(D)(E)	56 (A)(B)(C)(D)(E)
7 (A)(B)(C)(D)(E)	32 (A)(B)(C)(D)(E)	57 (A)(B)(C)(D)(E)
8 (A)(B)(C)(D)(E)	33 (A)(B)(C)(D)(E)	58 (A)(B)(C)(D)(E)
9 (A)(B)(C)(D)(E)	34 (A)(B)(C)(D)(E)	59 (A)(B)(C)(D)(E)
10 (A)(B)(C)(D)(E)	35 (A)(B)(C)(D)(E)	60 (A)(B)(C)(D)(E)
11 (A)(B)(C)(D)(E)	36 (A)(B)(C)(D)(E)	61 (A)(B)(C)(D)(E)
12 (A)(B)(C)(D)(E)	37 (A)(B)(C)(D)(E)	62 (A)(B)(C)(D)(E)
13 (A)(B)(C)(D)(E)	38 (A)(B)(C)(D)(E)	63 (A)(B)(C)(D)(E)
14 (A)(B)(C)(D)(E)	39 (A)(B)(C)(D)(E)	64 (A)(B)(C)(D)(E)
15 (A)(B)(C)(D)(E)	40 (A)(B)(C)(D)(E)	65 (A)(B)(C)(D)(E)
16 (A)(B)(C)(D)(E)	41 (A)(B)(C)(D)(E)	66 (A)(B)(C)(D)(E)
17 (A)(B)(C)(D)(E)	42 (A)(B)(C)(D)(E)	67 (A)(B)(C)(D)(E)
18 (A)(B)(C)(D)(E)	43 (A)(B)(C)(D)(E)	68 (A)(B)(C)(D)(E)
19 (A)(B)(C)(D)(E)	44 (A)(B)(C)(D)(E)	69 (A)(B)(C)(D)(E)
20 (A)(B)(C)(D)(E)	45 (A)(B)(C)(D)(E)	70 (A)(B)(C)(D)(E)
21 (A)(B)(C)(D)(E)	46 (A)(B)(C)(D)(E)	71 (A)(B)(C)(D)(E)
22 (A)(B)(C)(D)(E)	47 (A)(B)(C)(D)(E)	72 (A)(B)(C)(D)(E)
23 (A)(B)(C)(D)(E)	48 (A)(B)(C)(D)(E)	73 (A)(B)(C)(D)(E)
24 (A)(B)(C)(D)(E)	49 (A)(B)(C)(D)(E)	74 (A)(B)(C)(D)(E)
25 (A)(B)(C)(D)(E)	50 (A)(B)(C)(D)(E)	75 (A)(B)(C)(D)(E)

DO NOT WRITE IN THIS AREA

QUESTIONS 76–120

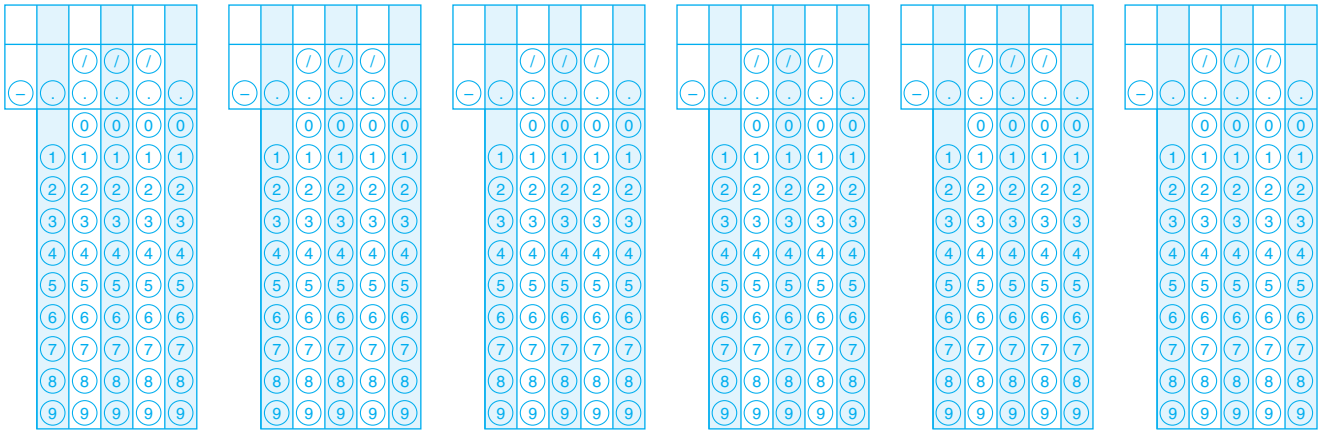
Be sure each mark is dark and completely fills the circle. If a question has only four answer options, do not mark option E.

76	A	B	C	D	E	91	A	B	C	D	E	106	A	B	C	D	E
77	A	B	C	D	E	92	A	B	C	D	E	107	A	B	C	D	E
78	A	B	C	D	E	93	A	B	C	D	E	108	A	B	C	D	E
79	A	B	C	D	E	94	A	B	C	D	E	109	A	B	C	D	E
80	A	B	C	D	E	95	A	B	C	D	E	110	A	B	C	D	E
81	A	B	C	D	E	96	A	B	C	D	E	111	A	B	C	D	E
82	A	B	C	D	E	97	A	B	C	D	E	112	A	B	C	D	E
83	A	B	C	D	E	98	A	B	C	D	E	113	A	B	C	D	E
84	A	B	C	D	E	99	A	B	C	D	E	114	A	B	C	D	E
85	A	B	C	D	E	100	A	B	C	D	E	115	A	B	C	D	E
86	A	B	C	D	E	101	A	B	C	D	E	116	A	B	C	D	E
87	A	B	C	D	E	102	A	B	C	D	E	117	A	B	C	D	E
88	A	B	C	D	E	103	A	B	C	D	E	118	A	B	C	D	E
89	A	B	C	D	E	104	A	B	C	D	E	119	A	B	C	D	E
90	A	B	C	D	E	105	A	B	C	D	E	120	A	B	C	D	E

For Students Taking AP Biology

Write your answer in the boxes at the top of the griddable area and fill in the corresponding circles. Mark only one circle in any column. You will receive credit only if the circles are filled in correctly.

121 122 123 124 125 126



ETS USE ONLY

SELECTED MEDIA EXAMS	R	W	O	OTHER EXAMS	R	W	O
PT02				TOTAL			
PT03				Subscore (if applicable)			
PT04				Subscore (if applicable)			

Exam		0 1 2 3 4 5 6 7 8 9
		0 1 2 3 4 5 6 7 8 9
Exam		0 1 2 3 4 5 6 7 8 9
		0 1 2 3 4 5 6 7 8 9

DO NOT WRITE IN THIS AREA

COMPLETE THIS AREA ONLY ONCE.

Q. YOUR MAILING ADDRESS Use the address abbreviations from your AP Student Pack. Fill in only one circle per column. Indicate a space in your address by leaving a blank box; do not grid that column.

STREET ADDRESS (include street number, street name, apartment number, etc.)

CITY

ZIP OR POSTAL CODE

COUNTRY CODE

STATE

AK	HI	MI	NY	VT	
AL	IA	MN	OH	WA	
AR	ID	MO	OK	WI	
AZ	IL	MS	OR	WV	
CA	IN	MT	PA	WY	
CO	KS	NC	RI	Puerto Rico	
CT	KY	ND	SC		
DC	LA	NE	SD	AA	
DE	MA	NH	TN	AE	
FL	MD	NJ	TX	AP	
GA	ME	NM	UT	Other	
		NV	VA		

U. STUDENT SEARCH SERVICE®

Colleges and scholarship programs may request your information to inform you of educational opportunities and financial aid.

Would you like us to supply your information?

◯ Yes ◯ No

If you don't answer and previously chose to participate in this service, we will continue providing your information.

V. SEX

◯ Female ◯ Male

W. WHICH LANGUAGE DO YOU KNOW BEST?

◯ English

◯ English and another language about the same

◯ Another language

X. ETHNICITY/RACE

◯ American Indian or Alaska Native
◯ Asian, Asian American or Pacific Islander
◯ Black or African American
◯ Mexican or Mexican American
◯ Puerto Rican
◯ Other Hispanic, Latino or Latin American
◯ White
◯ Other

Y. PARENTAL EDUCATION LEVEL

Father/ Male Guardian	Mother/ Female Guardian	
◯	◯	Grade school
◯	◯	Some high school
◯	◯	High school diploma or equivalent
◯	◯	Business or trade school
◯	◯	Some college
◯	◯	Associate or two-year degree
◯	◯	Bachelor's or four-year degree
◯	◯	Some graduate or professional school
◯	◯	Graduate or professional degree

R. FOR STUDENTS OUTSIDE THE UNITED STATES ONLY

◯ If your address does not fit in the spaces provided in Item Q, fill in as many circles as you can, then fill in the circle in Item R and print the remainder of your address in the spaces provided.

Address	City	State or Province	Country	ZIP or Postal Code

S. STUDENT IDENTIFIER (Student ID Number)

T. EMAIL ADDRESS By providing your email address, you are granting the College Board permission to use your email in accordance with the policies in the *2013-14 Bulletin for AP Students and Parents*.

Section I: Multiple-Choice Questions

This is the multiple-choice section of the 2014 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.)

PLACE SEAL HERE

AP® Biology Exam

SECTION I: Multiple Choice and Grid-In

2014

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

At a Glance

Total Time
1 hour, 30 minutes
Number of Questions
58
Percent of Total Score
50%
Writing Instrument
Pencil required
Electronic Device
Four-function calculator (with square root)

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.

PLACE SEAL HERE

PLACE SEAL HERE
DO NOT seal answer sheet inside

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 (ºC + 273)

Surface Area and Volume

Volume of a Sphere

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

Volume of a Rectangular Solid

$$V = \ell w h$$

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

$A = \sum$ 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)

$$C_i V_i = C_f V_f$$

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
53 Multiple-Choice Questions
5 Grid-In Questions
Time—90 Minutes

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. The lionfish is a venomous fish found primarily in the Red Sea and the Indian Ocean. In the 1990s, lionfish were accidentally released into the Atlantic Ocean, where they found abundant resources and favorable environmental conditions. Which of the following scenarios is most likely to result in the lionfish having a major impact on the communities into which they were introduced?

   (A) With no natural predators, the lionfish population will become very large.
   (B) Some native species of invertebrates will develop a resistance to lionfish venom.
   (C) Random mating will allow the lionfish population to reach Hardy-Weinberg equilibrium.
   (D) A virus that specifically infects lionfish will become more prevalent.

2. Cell communication is critical for the function of both unicellular and multicellular eukaryotes. Which of the following is likely true of cell signaling?

   (A) Cell signaling uses the highest molecular weight molecules found in living cells.
   (B) Cell signaling has largely been replaced by other cell functions in higher mammals.
   (C) Similar cell signaling pathways in diverse eukaryotes are evidence of conserved evolutionary processes.
   (D) Cell signaling functions mainly during early developmental stages.

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3. A colony of termites was exposed to an atmosphere of 100 percent oxygen for three days. The insects were not immediately harmed by the treatment, but the protozoa that lived in the termites' guts were eliminated. The treated termites continued to behave normally and to eat wood, but they began to starve after a short time.

   When the treated termites were instead fed wood contaminated with the feces of untreated termites, the treated termites regained the ability to digest wood and no longer starved. The best analysis of the results of the experiment is that

   (A) infection with protozoa causes the termites to switch to fermentation
   (B) cooperative interactions between the termites and the protozoa allow termites to extract energy from wood to survive
   (C) the termite immune system eliminates protozoa from the gut
   (D) termites digest protozoa as their main source of energy

4. Ethylene is an organic compound produced by ripening fruits. In a controlled experiment, researchers found that ethylene gas stimulated the ripening process in newly harvested fruits. Which of the following describes the most likely connection between natural ethylene production and fruit ripening?

   (A) As a result of metabolic inactivity, newly harvested fruits are unable to absorb ethylene gas from the atmosphere.
   (B) Ethylene gas is a chemical signal through which ripening fruits trigger the ripening process in other fruits.
   (C) Because of normal phenotypic variation, only some of the fruits in a given generation are expected to produce ethylene gas.
   (D) The rate of ethylene gas production by ripening fruits is an indicator of the relative age of an ecosystem.

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5. Water in a pond contaminated with the weed killer atrazine is suspected of inhibiting metamorphosis in northern leopard frogs. A team of scientists collected fertilized northern leopard frog eggs from a different pond that is not contaminated. Which of the following is the best experimental design to determine whether atrazine is responsible for inhibiting metamorphosis in northern leopard frogs?

   (A) Place half of the fertilized eggs in a pool of water with the same concentration of atrazine as the contaminated pond and place the other half of the fertilized eggs in a pool of water that has no atrazine. Monitor the development of the embryos through metamorphosis into adulthood.

   (B) Place all of the fertilized eggs in a pool of pond water with the same concentration of atrazine as the contaminated pond and compare the number of frogs that reach metamorphosis to those that reach adulthood in the contaminated pond.

   (C) Allow all fertilized eggs to develop into adults. Expose one-third of the frogs to one-half of the concentration of atrazine in the contaminated pond and expose another one-third of the frogs to the same concentration of atrazine as the contaminated pond. Leave the last one-third of the frogs in water with no atrazine and note any adverse changes in the physical condition of the atrazine-treated frogs in three months.

   (D) Divide the fertilized eggs into three groups and expose each group to a different concentration of atrazine. Release the eggs back into the contaminated pond and check for metamorphosis after three months.

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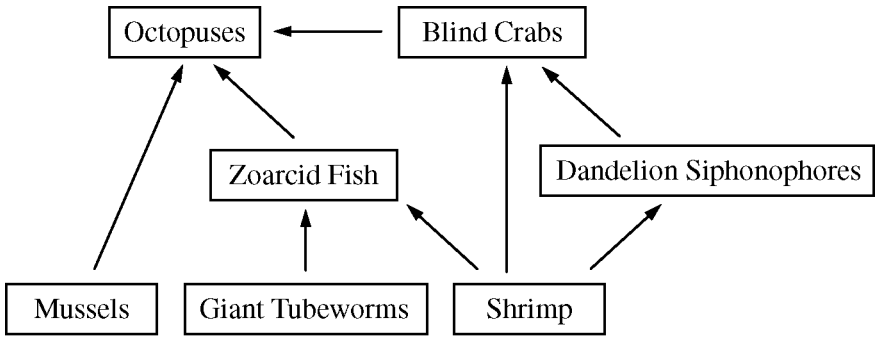
Questions 6-10



The food web above represents feeding relationships in a biological community near a deep-sea hydrothermal vent. Hydrothermal vents are geysers on the seafloor that gush super-heated, mineral-rich water. The seawater surrounding hydrothermal vents typically contains carbon dioxide (CO_2), molecular hydrogen (H_2), hydrogen sulfide (H_2S), and methane (CH_4). Sunlight, however, fails to reach the seafloor where deep-sea hydrothermal vents are located.

As part of an investigation, researchers collected living specimens from an area near a deep-sea hydrothermal vent. Mussels in the collection were found to be dependent on molecular hydrogen in seawater. Also, the researchers discovered multiple species of bacteria living in the gills of the mussels. Mussels use gills for filter-feeding and gas exchange with the surrounding seawater. On the basis of their experimental results, the researchers hypothesized that some bacteria living in the gills of the mussels are capable of chemosynthesis.

6. Which of the following best explains how biological communities near deep-sea hydrothermal vents can exist in a habitat lacking sunlight?

   (A) Environmental conditions on some distant planets resemble those experienced by organisms living near hydrothermal vents.
   (B) Heterotrophs metabolize carbon-containing compounds produced by the photosynthetic organisms that live on the seafloor.
   (C) Some organisms rely on energy captured from inorganic compounds to drive basic biological processes.
   (D) Some organisms that can tolerate high temperatures are single celled, whereas others are multicellular.

7. Based on an analysis of the food web, an observation that deep-sea bacteria consume molecular hydrogen (H_2) is most relevant to resolving which of the following apparent contradictions?

   (A) Water gushing from deep-sea hydrothermal vents can be as hot as 400°C, which is a lethal temperature for most organisms.
   (B) Some deep-sea organisms appear to be primary consumers, but no plants live near the hydrothermal vents.
   (C) Zoarcid fish are thought to be aggressive predators, but they are frequently described as being lazy swimmers.
   (D) Some tissues of tubeworms contain hemoglobin, which is an oxygen-carrying molecule, but there is little free oxygen at this depth.

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8. Researchers are investigating the evolutionary relationships among organisms found near deep-sea hydrothermal vents and similar organisms found closer to the ocean surface. Which of the following scientific questions is most relevant to the investigation?

   (A) What are the nucleotide sequences of ribosomal RNA genes that are found in the genomes of the different species?
   (B) What large-scale geological events have occurred recently in the Mid-Atlantic Ocean?
   (C) Does water temperature at different ocean depths affect the relative levels of dissolved oxygen?
   (D) Do species found near deep-sea hydrothermal vents all have the same haploid number of chromosomes?

9. On the basis of the food web, which of the following members of a deep-sea biological community is most likely to also have a symbiotic relationship with chemosynthetic organisms?

   (A) Octopuses
   (B) Blind crabs
   (C) Zoarcid fish
   (D) Shrimp

10. To refine their model of deep-sea biological communities, the researchers investigated areas of the seafloor that are distant from any active hydrothermal vents. Which of the following is the best interpretation of the observation that some octopus species are only found near active hydrothermal vents?

    (A) Octopuses depend indirectly on inorganic compounds in the seawater surrounding hydrothermal vents.
    (B) Organisms capable of moving across the seafloor are more difficult to observe than are organisms that are rooted in place.
    (C) Genetic bottleneck events in isolated areas of the deep ocean adversely affect some octopus populations but not others.
    (D) Biomass in a typical marine food web is expected to be greater in higher trophic levels than in lower trophic levels.

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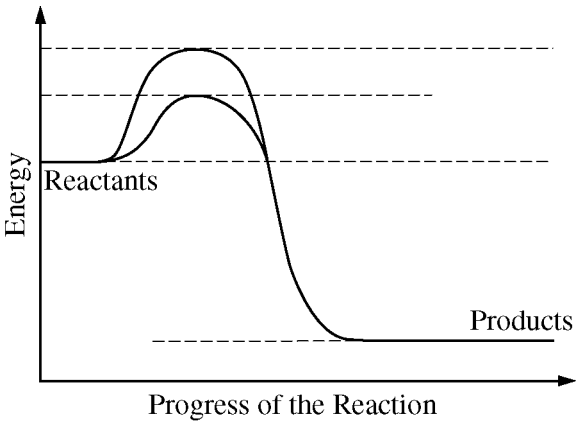
11. On a large volcanic island, researchers are studying a population of annual herbaceous plants. Which of the following observations best supports the prediction that speciation will occur within the existing plant population?

(A) Individuals of the species sometimes reproduce asexually by producing runners.
(B) Lava has separated the population into two areas: an upland forest and a lowland marsh.
(C) Multiple groups of birds depend on the fruit produced by the plants as a source of food.
(D) The plants produce more seeds during warm summers than they do during cool summers.

12. Individuals with an inherited autosomal recessive disorder called primary ciliary dyskinesia (PCD) often have severe respiratory problems due to defective cilia. Males with PCD are often sterile because they produce sperm with defective flagella. Which of the following most likely explains the effect of the recessive allele?

(A) The mitochondria are defective and do not produce sufficient protein to synthesize microtubules in the cilia and flagella.
(B) The plasma membrane of the alveoli is not permeable to carbon dioxide during respiration because it is too hydrophobic.
(C) The Golgi bodies secrete an enzyme that destroys the proteins in the flagella and cilia.
(D) The cells do not produce functional motor proteins in flagella and cilia.

13. The diagram below shows energy changes in a specific chemical reaction with and without the addition of an enzyme to the reaction.



Which of the following questions can best be answered by the diagram?

(A) Does the addition of an enzyme reduce the activation energy required for a reaction?
(B) Does the addition of an enzyme result in the formation of covalent bonds?
(C) Does the addition of an enzyme produce a greater amount of products?
(D) Does the addition of an enzyme change the pathway for the reaction?

14. The salinity of a small inland lake has recently started to increase. Researchers are planning to study the lake over several decades to investigate how freshwater organisms survive significant changes in their natural habitat. Which of the following physiological mechanisms will the researchers most likely observe among the surviving organisms in the lake?

(A) Prokaryotic organisms will use various mechanisms to counteract swelling of cells as a result of increased water uptake.
(B) Single-celled organisms will use various mechanisms to counteract the increased flow of water from cells to the environment.
(C) Eukaryotic organisms will use various mechanisms to counteract the diffusion of positively charged ions across the cell membrane.
(D) Multicellular organisms will use various mechanisms to counteract the loss of cell adhesion as a result of calcium deficiencies.

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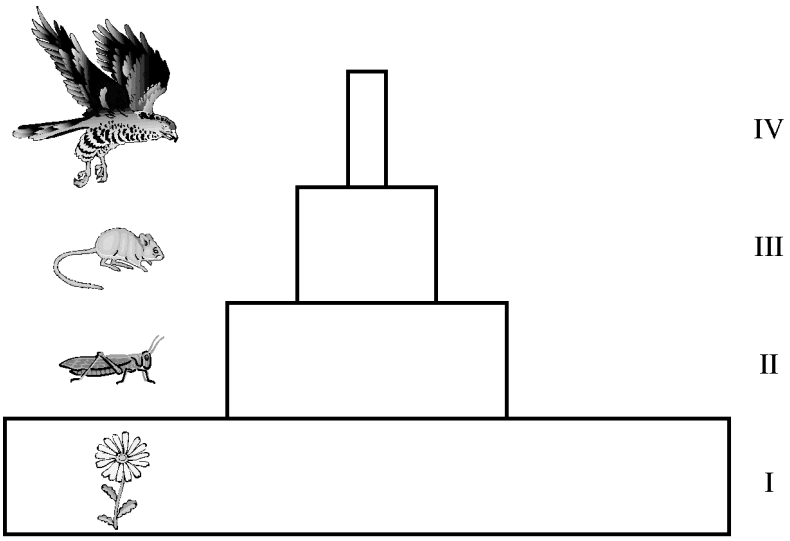

15. Assume there are 50,000 joules (J) of energy available in trophic level II in the figure. According to the conventional model of energy flow in ecosystems, which of the following statements correctly describes the flow of energy in the system?

(A) Trophic level I generates a maximum of 50,000 J of energy.
(B) Trophic level I has approximately 5,000 J of available energy.
(C) Trophic level III has approximately 50 J of available energy.
(D) Trophic level IV has approximately 500 J of available energy.

Questions 16-20

The three-spined stickleback (*Gasterosteus aculeatus*) is a small fish found in both marine and freshwater environments. Marine stickleback populations consist mainly of individuals with armor-like plates covering most of their body surface (completely plated). Approximately 10,000 years ago, some marine sticklebacks colonized freshwater environments. After many generations in the freshwater environments, the freshwater stickleback populations lacked the armor plating (low plated) typical of marine stickleback populations.

Over the period between 1957 and 2005, one freshwater population, in Lake Washington, a lake in a coastal region of the northwestern United States, changed from having a majority of individuals of the low-plated phenotype to having more individuals of the completely-plated phenotype than of the low-plated phenotype. Figure 1 shows the distribution of plated phenotypes in Lake Washington sticklebacks at four time points between 1957 and 2005.

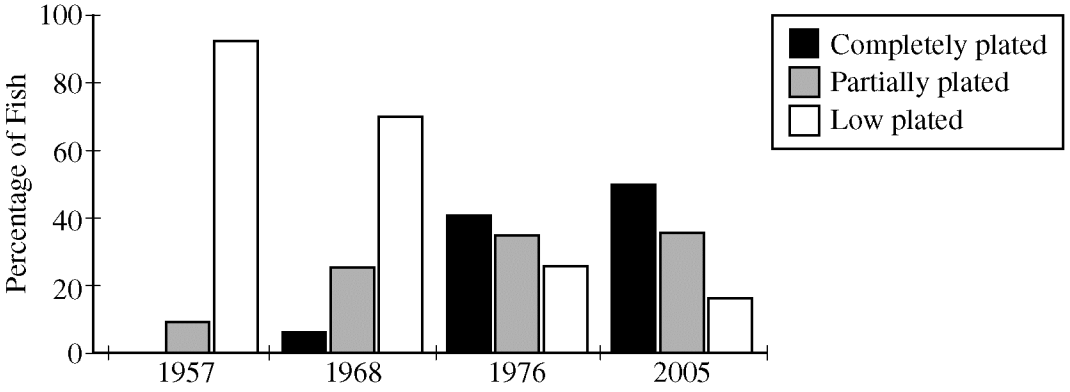

Figure 1. Armor plating phenotypes in Lake Washington stickleback population

A single gene, *ectodysplasin* (*EDA*), is thought to be responsible for the variation in the number of armor plates in sticklebacks. Figure 2 shows a phylogenetic tree constructed by comparing DNA sequences of the *EDA* gene from a number of stickleback populations with low-plated or completely plated phenotypes. Figure 3 shows a phylogenetic tree constructed by comparing the sequences of 25 genes that were randomly selected from the same populations as shown in Figure 2. In both figures, shaded populations display the completely plated phenotype.

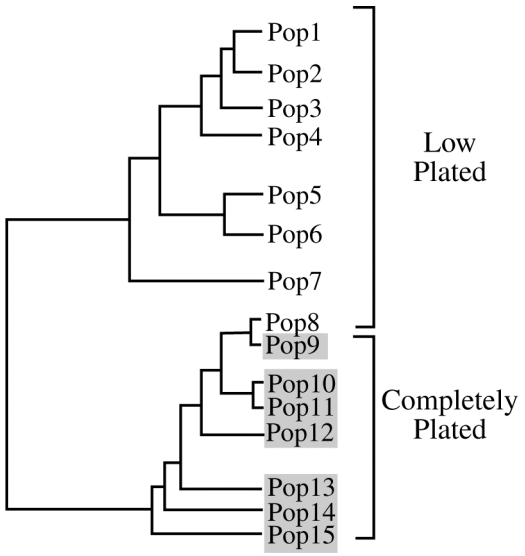

Figure 2. Phylogeny based on *EDA* gene only

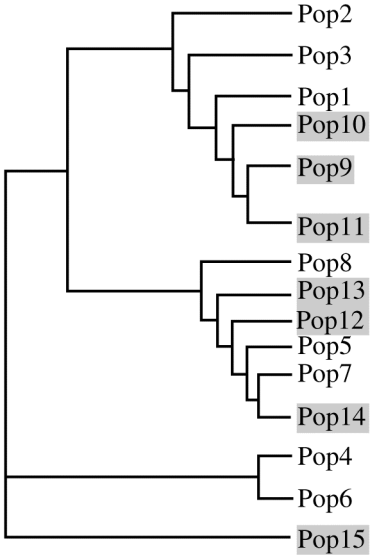

Figure 3. Phylogeny based on 25 random genes

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16. Which of the following best explains the differences in the armor of the Lake Washington stickleback population summarized in Figure 1 ?

(A) Analysis of somatic cells using chromosomal staining and light microscopy indicates that stickleback fish have a diploid number of 42.

(B) Stickleback males from natural freshwater populations are typically more aggressive when competing for mates than are stickleback males from laboratory-bred populations.

(C) Fish exhibiting the low-plated phenotype were selected against in the Lake Washington stickleback population over the last 50 years.

(D) Migration of individuals from other freshwater environments to Lake Washington led to gene flow between populations that were once geographically isolated.

17. A completely-plated stickleback from a marine population was mated to a low-plated stickleback from a freshwater population. The resulting F_1 hybrids all displayed a completely plated phenotype. When the F_1 hybrids were allowed to interbreed, the resulting F_2 generation included completely plated offspring and low-plated offspring in an approximate 3:1 ratio. Which of the following conclusions is best supported by the results of the breeding experiments?

(A) Phenotypic variation in the F_2 generation suggests that armor morphology is controlled by many alleles of a single gene.

(B) The completely-plated phenotype is controlled by a dominant allele of a single gene.

(C) Armor loss is an acquired characteristic that is affected by one or more environmental factors.

(D) Patterns of armor plating in stickleback populations are regulated by sex-specific signals.

18. Prior to 1960, Lake Washington was highly polluted and underwater visibility was limited to one or two meters. In the late 1960s, a large cleanup effort reduced pollution, resulting in visibility that increased to six to seven meters by 1976. Which of the following best explains how the change in underwater visibility affected armor plating in Lake Washington sticklebacks between 1957 and 1976 ?

(A) Higher visibility allowed sticklebacks to increase their food consumption to make armor production easier.

(B) Higher visibility made the sticklebacks more susceptible to large-toothed predators in the lakes, giving complete armor a selective advantage.

(C) Clearer water allowed sunlight to penetrate to deeper depths, so the sticklebacks had to increase the amount of armor to protect themselves from the resulting increase in water temperature.

(D) Clearer water contained fewer of the molecular building blocks needed for armor production, so sticklebacks showed a reduction in the amount of armor.

19. Evolution of a new trait typically takes many generations. Yet a dramatic shift in the extent of armor plating in the Lake Washington stickleback population occurred in the 50 years following the cleanup of the lake. Which of the following best describes the mechanism of the rapid evolution of the armor phenotype in the Lake Washington sticklebacks?

(A) Pollutants in Lake Washington forced the sticklebacks to increase their mutation rate.

(B) The rapid change in the Lake Washington ecosystem required individual sticklebacks to evolve complete armor quickly.

(C) The increase in visibility in Lake Washington allowed sticklebacks to visually select mates with low armor.

(D) New selective pressures favored individuals with the plated phenotype, causing the plated allele frequency in the population to quickly increase.

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20. The phylogenetic trees in Figures 2 and 3 depict two different phylogenies of the same populations of sticklebacks. Which of the following questions will best help determine which tree represents the most accurate phylogeny?

(A) Is the *EDA* gene as representative of the differences between the populations as the 25 random genes that were examined for Figure 3 ?

(B) Are the low-plated populations found only in freshwater and the high-plated populations found only in saltwater environments?

(C) Is the common ancestor of the organisms represented in Figure 2 different from the common ancestor of the organisms represented in Figure 3 ?

(D) Is the expression level of the *EDA* gene analyzed in Figure 2 significantly greater than the expression levels of the 25 genes analyzed in Figure 3 ?

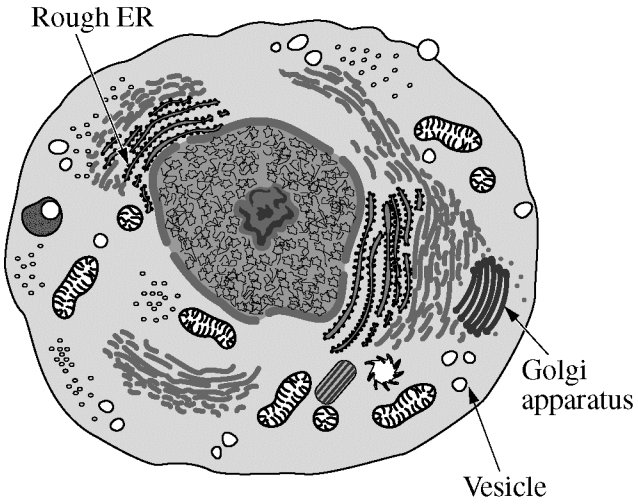
21. Which of the following occurs in all species of living organisms and may lead to an increase in genetic variation?

(A) Mutations in the genome
(B) Crossing-over in meiosis
(C) Random assortment of chromosomes
(D) Alternative splicing of mRNA

22. A researcher examining a root tip observes a plant cell with condensed sister chromatids, kinetochores with attached microtubules, and individual chromosomes that are aligned at the equatorial plate of the cell. Which of the following best describes what the next process will be in the cell?

(A) Homologous chromosomes (each with two sister chromatids) will move toward opposite poles of the cell.
(B) Paired chromatids will separate, and the new daughter chromosomes will move toward opposite poles of the cell.
(C) The nuclear envelope will break down, and the spindle will begin to form.
(D) The chromatin will decondense, and the daughter cell will enter interphase.

23. The figure below illustrates a eukaryotic cell. Which of the following best describes how the three structures indicated by the arrows work together?



(A) To synthesize lipids and modify toxic substances in order to render them harmless
(B) To synthesize and isolate proteins for secretion or for use in the cell
(C) To catabolize nutrients and produce ATP for intracellular energy storage
(D) To synthesize all ribosomal proteins

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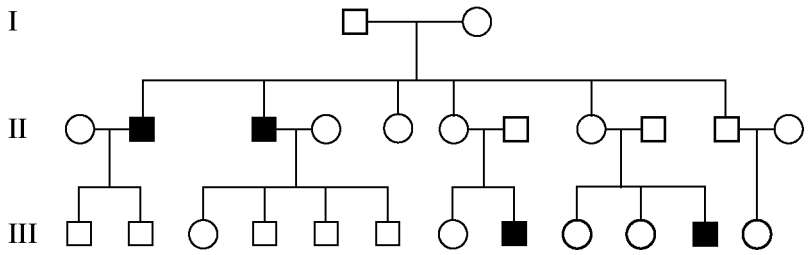
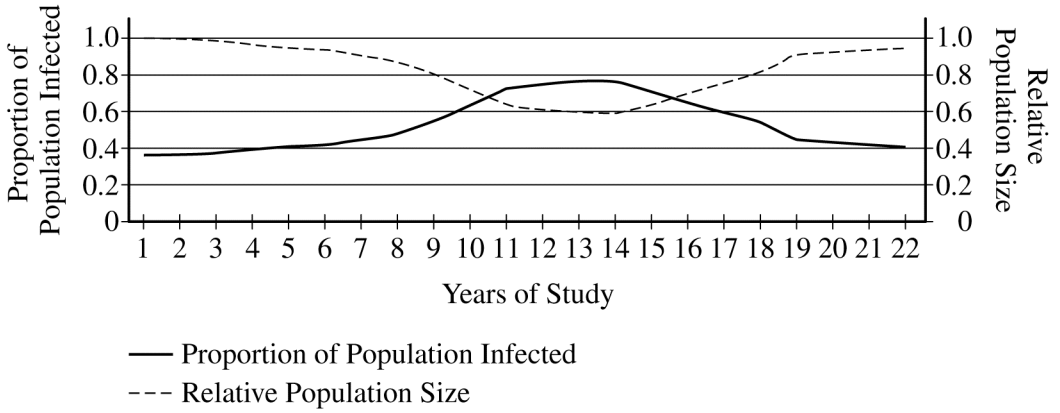
24. In the following human pedigree, squares represent males, circles represent females, and shaded symbols indicate individuals affected with a disorder.



One of the affected males from the third generation has a child with a female who is a carrier. For the pedigree shown above, which of the following best expresses the probability that the couple's first son will be affected with the disorder?

(A) 25%
(B) 50%
(C) 75%
(D) 100%

CHYTRIDIOMYCOSIS INFECTION IN A FROG POPULATION



25. Chytridiomycosis is a potentially lethal fungal infection that adversely affects some frog populations. The incidence and severity of the fungal infection can vary over time. Which of the following statements best describes the changes in the frog population that are depicted in the model above?

(A) The fungus that infected the frog population was initially virulent but it later became harmless. Based on the trend over the past few years of the study, the fungus has become extinct.

(B) Infected individuals gradually died out, and genetically resistant individuals became more common. The frog population recovered because of the increased frequency of resistant individuals.

(C) The patterns of the curves on the graph indicate a sudden increase in the severity of the fungal infection. A large proportion of the frog population died because the individuals could not evolve fast enough.

(D) The size of the frog population decreased sharply upon initial contact with the fungus. The fungus eventually became symbiotic with individual frogs, and the frog population began to recover.

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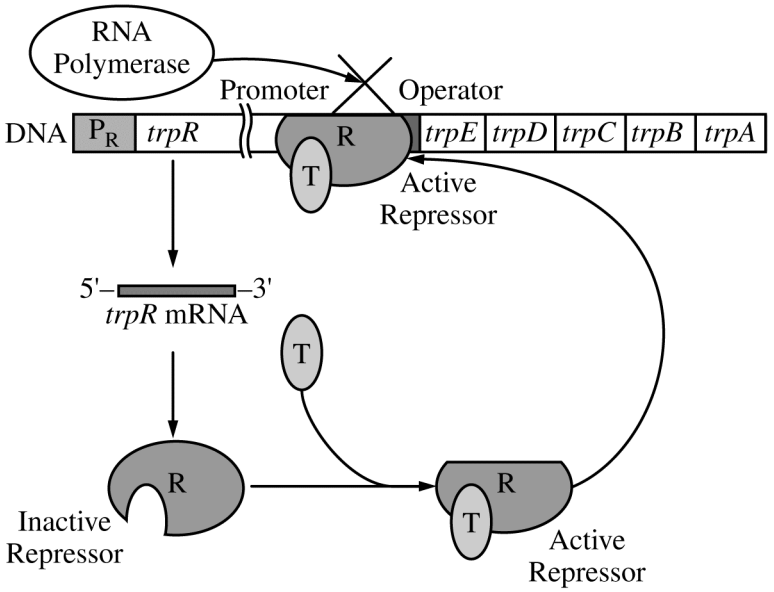

R	= Repressor molecule
T	= Tryptophan molecule
P_R	= Promoter for the *trpR* gene
trpR	= Repressor gene
Operator	= Binding site for repressor molecule

26. The *Trp* operon is a coordinately regulated group of genes (*trpA–trpE*) that are required for tryptophan biosynthesis in *E. coli*. Based on the figure above, which of the following correctly describes the regulation of the *Trp* operon?

(A) In the absence of tryptophan, the repressor is active and binds to the *Trp* operator, preventing RNA polymerase from transcribing the operon.
(B) In the presence of tryptophan, the repressor is active and binds to the *Trp* operator, preventing RNA polymerase from transcribing the operon.
(C) In the absence of tryptophan, the *trpR* gene is inactive, preventing the production of the repressor that blocks expression of the operon.
(D) In the presence of tryptophan, the *trpR* gene is inactive, preventing the production of the repressor that blocks expression of the operon.

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27. The pesticide DDT was widely used in the 1940s as a method of insect control. In the late 1950s the first DDT-resistant mosquitoes were discovered, and eventually DDT-resistant mosquitoes were found globally. When DDT is used now, the development of DDT resistance in mosquito populations occurs in months rather than years.

    Which of the following best explains the observations concerning DDT resistance in mosquitoes?

    (A) Competition for limited resources causes mosquitoes to migrate to geographical areas that have richer supplies of DDT.
    (B) The proportion of DDT-resistant mosquitoes in a population remains constant due to the metabolic costs of DDT utilization.
    (C) Natural selection favors DDT-resistant mosquitoes that are already present in a population when DDT exposure occurs.
    (D) DDT is a chemical signal that delays normal reproductive cycles in many mosquito populations.

28. Two nutrient solutions are maintained at the same pH. Actively respiring mitochondria are isolated and placed into each of the two solutions. Oxygen gas is bubbled into one solution. The other solution is depleted of available oxygen. Which of the following best explains why ATP production is greater in the tube with oxygen than in the tube without oxygen?

    (A) The rate of proton pumping across the inner mitochondrial membrane is lower in the sample without oxygen.
    (B) Electron transport is reduced in the absence of a plasma membrane.
    (C) In the absence of oxygen, oxidative phosphorylation produces more ATP than does fermentation.
    (D) In the presence of oxygen, glycolysis produces more ATP than in the absence of oxygen.

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Questions 29-32

Table I shows the results of breeding experiments to examine the inheritance of flower color (purple versus white) and pod shape (inflated versus constricted). For the crosses recorded in Table I, true-breeding parents were crossed to produce F_1 offspring, which were then testcrossed to homozygous recessive individuals. Table II shows the results of computer-simulated crosses to model the inheritance of leaf shape (broad versus narrow) and flower color (purple versus white).

TABLE I: RESULTS FROM CROSSES WITH PEA PLANTS

Parental Cross	Phenotypes of F_1 Offspring	Phenotypes of Testcross Offspring (numbers of individuals)			
Purple × White	Purple	Purple (461)		White (468)	
Inflated × Constricted	Inflated	Inflated (593)		Constricted (588)	
Purple, Inflated × White, Constricted	Purple, Inflated	Purple, Inflated (315)	Purple, Constricted (312)	White, Inflated (320)	White, Constricted (317)

TABLE II: RESULTS OF COMPUTER-SIMULATED CROSSES

Parental Cross	Phenotypes of F_1 Offspring	Phenotypes of Testcross Offspring (numbers of individuals)			
Broad × Narrow	Broad	Broad (4870)		Narrow (4862)	
Purple × White	Purple	Purple (4253)		White (4259)	
Broad, White × Narrow, Purple	Broad, Purple	Broad, White (672)	Broad, Purple (75)	Narrow, White (61)	Narrow, Purple (664)

29. Based on the data in Table I, which of the following best explains why there are no individuals with constricted pods in the F_1 generation?

(A) Inflated pod shape is dominant to constricted pod shape.
(B) The inflated-pod offspring in the F_1 generation are homozygous.
(C) Constricted pod shape typically arises from a new mutation in the F_1 generation.
(D) The constricted-pod offspring are carriers for the inflated pod shape allele.

30. In Table I, the ratio of phenotypes in the offspring from the testcross with F_1 plants that had purple flowers and inflated pods suggests that the genes for flower color and pod shape are located

(A) close together on the same autosome
(B) on the X chromosome
(C) on different chromosomes
(D) on a mitochondrial chromosome

31. Which of the following provides the best justification for an assumption that might have been used in the computer simulation (Table II) ?

(A) The broad allele is recessive to the narrow allele because broad leaves appear in every generation.
(B) The purple allele is dominant to the white allele because all the offspring from the cross of purple-flowered and white-flowered plants had purple flowers.
(C) The narrow allele is codominant with the purple allele because the purple-flower trait and the narrow-leaf trait segregate together.
(D) The white allele is dominant to both the broad and narrow alleles because plants with either type of leaf shape can have white flowers.

32. In Table II, the F_1 offspring of the cross between broad-leaved, white-flowered plants with narrow-leaved, purple-flowered plants have a phenotype that differs from that of either parent. However, many testcross offspring have the same phenotype as one of the two plants in the parental cross, but relatively few testcross offspring have the same phenotype as the F_1 offspring. Which of the following best explains the observation?

(A) Recombination between the leaf-shape and flower-color genes resulted in chromosomes carrying a dominant allele of both genes.
(B) Recombination between the broad and narrow alleles of the leaf-shape gene resulted in chromosomes carrying three different alleles at the same genetic locus.
(C) Independent assortment of homologous chromosomes resulted in the combinations of alleles present in the parental generation.
(D) The computer model cannot capture the possible assortments of gametes when multiple genes are considered.

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33. When a stimulus is applied to a receptor in the skin, an action potential is propagated along a neuron to the brain, where another signal is sent back to the muscle for a response.

Which of the following best describes what occurs when the action potential reaches a chemical synapse at the end of an axon?

(A) The action potential jumps from one axon to the next connecting axon.
(B) The action potential travels through the synapse to the next connecting dendrite.
(C) The action potential jumps the synapse to the next connecting dendrite.
(D) The action potential causes a release of neurotransmitters that travel across the synapse.

34. Methicillin-resistant *Staphylococcus aureus* (MRSA) can be a serious threat to human health. There is evidence that *S. aureus* infections are common in hospitals and that MRSA have become resistant to other antibiotics besides methicillin. This suggests that the rapid evolution of resistance in the bacteria poses a serious public-health challenge. Which of the following best explains the ability of MRSA to evade existing drug therapies?

(A) MRSA have very long generation times and very large population sizes.
(B) MRSA develop new alleles by intentionally introducing specific mutations that will give them a selective advantage over other bacteria.
(C) MRSA metabolize many drugs in their lysosomes and therefore evolve resistance at a high rate.
(D) MRSA exchange genetic material with other antibiotic-resistant bacteria, which can spread resistance in the *S. aureus* population.

GO ON TO THE NEXT PAGE.

	Diet	
	Before Change	After Change
Principal diet	Hay	Grain
Main type of carbohydrate supplied by diet	Cellulose	Starch
Abundance of *Streptococcus bovis* in the rumen	Low	High
Abundance of *Ruminococcus albus* in the rumen	High	Low
pH of rumen fluid	6 – 7	< 5.6
Clinical warning signs in cattle	None	Weakness

35. Researchers conducted a controlled experiment to investigate the effect of diet on the health of beef cattle. The initial hypothesis was that an abrupt change in diet will benefit beef cattle by reducing the sizes of bacterial populations living in the digestive systems of the cattle.

    In the experiment, the researchers determined the relative abundance of two bacterial species found in the rumen of cattle. The rumen is a part of the stomach that acts as a fermentation chamber in cattle and other ruminants. Shown in the table are the results from before and after an abrupt change in the cattle's diet. Based on the results, which of the following best explains why the initial hypothesis should be revised?

    (A) The diets were too similar, since cellulose and starch are both carbohydrates obtained from eating plants.
    (B) The abundance of one of the bacterial species increased in response to the change in diet.
    (C) The change in the diversity of microorganisms had no observable effect on cattle physiology.
    (D) The ability of rumen fluid to resist changes in pH counteracted the changes in microorganism diversity.

36. The table below describes the action of two genes involved in the regulation of nervous system development in the nematode *C. elegans*.

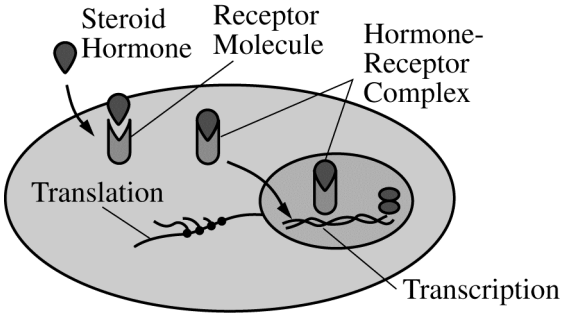
	Gene *A*	Gene *B*	Observation
Pattern 1	Inactive	Inactive	No neurons develop.
Pattern 2	Inactive	Active	No neurons develop.
Pattern 3	Active	Inactive	Greater-than-normal number of neurons develop.
Pattern 4	Active	Active	Normal number of neurons develop.

Which of the following claims is best supported by the data?

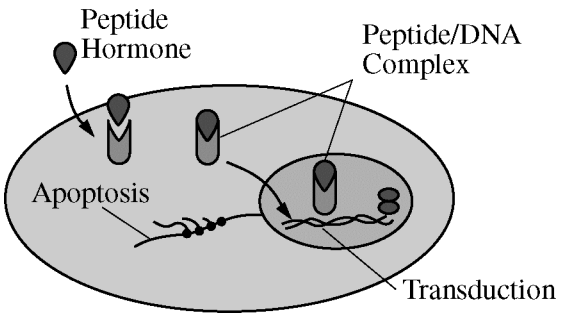
(A) Gene *A* promotes neuron development; gene *B* promotes programmed cell death in neuronal precursors.
(B) Gene *A* promotes programmed cell death in neuronal precursors; gene *B* promotes neuron development.
(C) Gene *B* must be active before gene *A* can function.
(D) Gene *B* must be inactive before gene *A* can function.

37. Which of the following diagrams best represents hormone-activated gene expression?

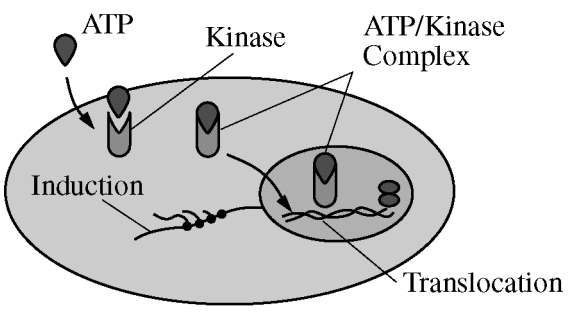
(A)



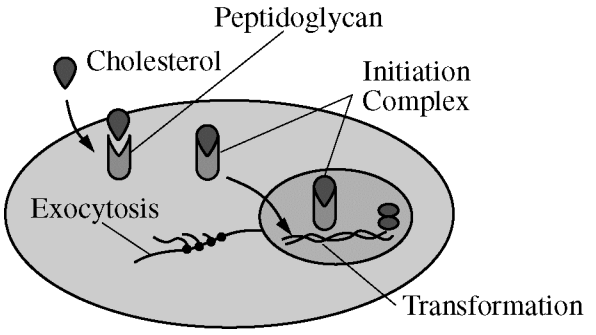
(B)



(C)



(D)



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38. The bacterium *Vibrio cholerae* is harmless unless a lysogenic bacteriophage provides the gene coding for the cholera toxin, which converts the bacterium to the virulent form that causes cholera. Which of the following best explains how the gene encoding cholera toxin becomes part of the bacterial genome?

(A) The bacteriophage inserts the toxin gene into the host cell DNA, and the gene is expressed with the rest of the host cell's genes.
(B) The bacteriophage makes copies of the toxin gene and expresses the copies inside the bacteriophage.
(C) The bacteriophage converts its toxin gene into mRNA, which is then translated by the host cell.
(D) The bacteriophage transforms itself into a self-replicating protein that can survive inside the host cell.

39. A species of snail lives in the intertidal zone along the coast of New England. The dark-colored variety of the species is more common in northern New England, the light-colored variety is more common two hundred miles away in southern New England, and both varieties are commonly found together in central New England. Which of the following best explains the observed distribution pattern of the snails?

(A) The founder effect suggests that dark-colored snails migrated from the southern regions to the north and established the populations found there.
(B) Genetic drift at the shell-color locus caused the northern population to become homozygous for the dark-color allele.
(C) The mutation rate is higher in the south, as the longer days expose the snails to more ultraviolet radiation than in the north.
(D) Dark-colored snails absorb more solar energy and so survive more readily in the colder northern waters.

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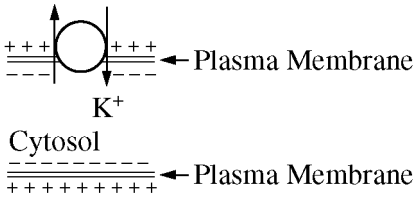
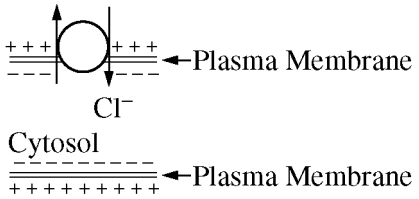
40. Which of the following representations best shows a portion of an axon at rest (before or after an action potential)?

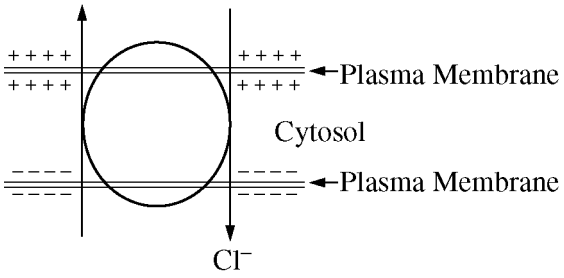
(A)



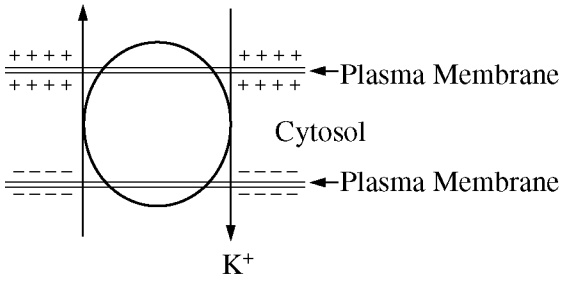
(B)



(C)



(D)



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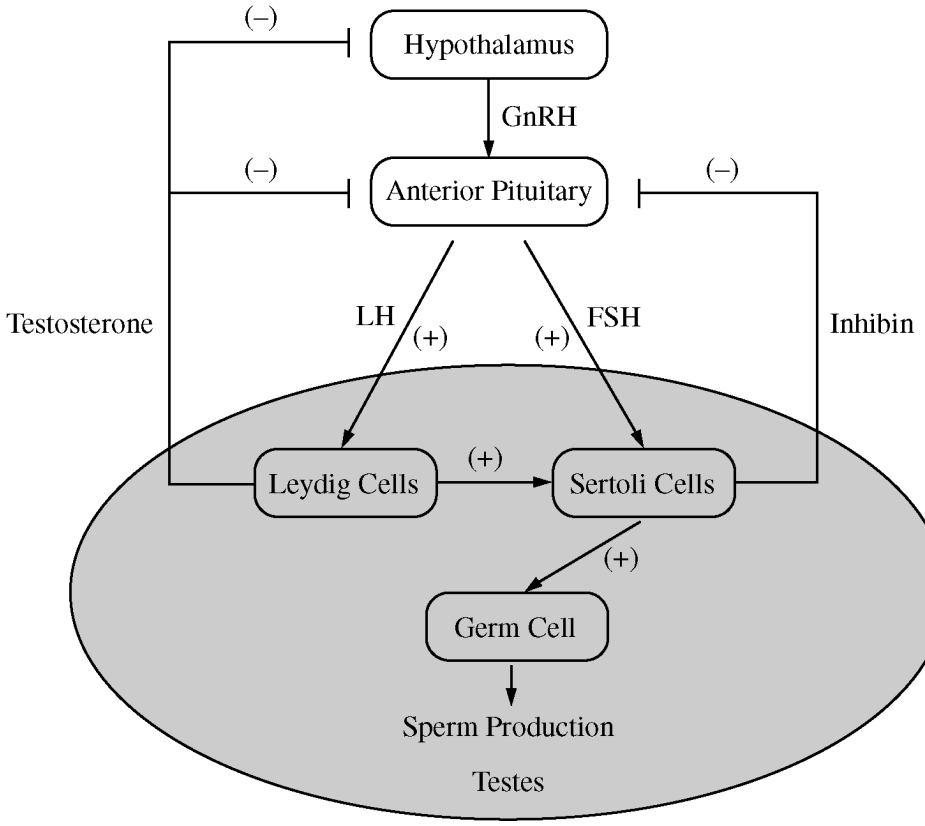
HORMONAL CONTROL OF MALE REPRODUCTIVE SYSTEM



41. Precise regulation of specific hormone levels is required for optimal sperm production in mammals, as summarized in the figure above. Anabolic-androgenic steroids (AAS) are synthetic variants of testosterone that are sometimes abused by persons who desire to enhance their athletic performance or alter their physique. Assuming that AAS function in the same way as naturally occurring testosterone, it is most likely that long-term abuse of AAS would

(A) stimulate FSH secretion
(B) stimulate testosterone production
(C) stimulate LH secretion
(D) reduce sperm production

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Questions 42-45

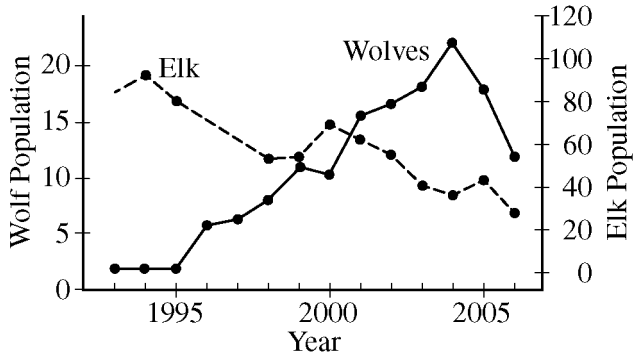

Figure 1. Wolf and Elk Population Sizes in Yellowstone National Park

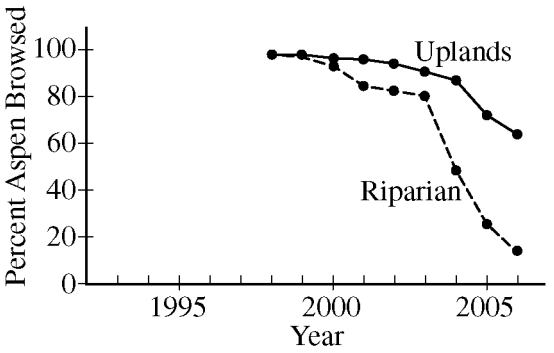

Figure 2. Browsing of Aspen in Yellowstone National Park

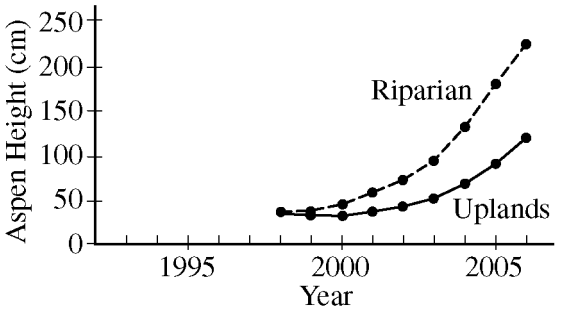

Figure 3. Growth of Aspen in Yellowstone National Park

Wolves, a top predator, were reintroduced to Yellowstone National Park in 1995 after a 50-year absence. In a multiyear study, the numbers of wolves and elk were monitored. The data are shown in Figure 1. In two different environments scientists monitored the percent of aspen trees browsed by herbivores (Figure 2) as well as the growth of the trees (Figure 3). The upland environments consist mostly of flat forested areas. The riparian environments are areas along streams with steep, wooded banks.

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42. Based on the data, which of the following is the best explanation for the changes in the elk population size between 2000 and 2005 ?

(A) The heights of aspen trees increased during that time period.
(B) Predation by wolves was higher than before 1995.
(C) The numbers of aspen trees increased during that time period.
(D) Wolf populations increased more rapidly in the upland areas.

43. Which of the following predictions about the community is most likely true?

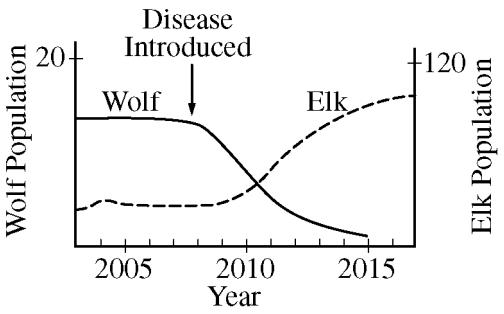
(A) A decrease in the elk population will cause wolves to feed on aspen trees.
(B) An increase in the wolf population will lead to a decrease in aspen growth.
(C) An increase in the growth of aspens will lead to a decrease in the wolf population.
(D) A decrease in the wolf population will lead to a decrease in the mean aspen height.

44. Based on the data, which of the following behaviors in elk could account for the differences between the percent of aspens browsed by herbivores and the height of aspen trees in riparian and upland environments?

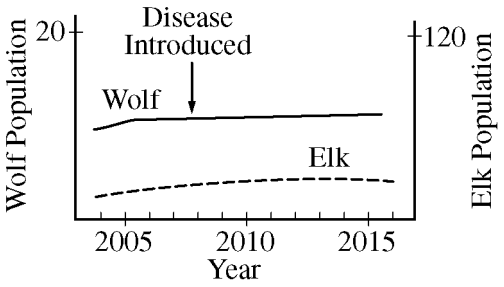
(A) Elk tend to avoid riparian areas where the steep, wooded riverbanks make it difficult to escape predators.
(B) Elk tend to prefer riparian areas where there is easy access to water.
(C) Elk tend to avoid upland areas where trees are too tall to be easily eaten.
(D) Elk tend to prefer upland areas where there are richer sources of mineral nutrients, such as potassium and iodine.

45. Which of the following models best predicts the effect on the ecosystem if a deadly communicable disease is introduced into the wolf population?

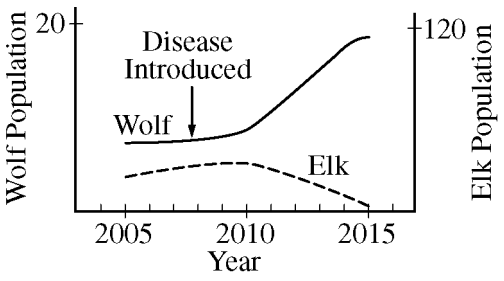
(A)



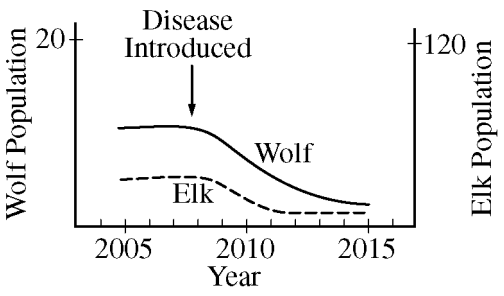
(B)



(C)



(D)



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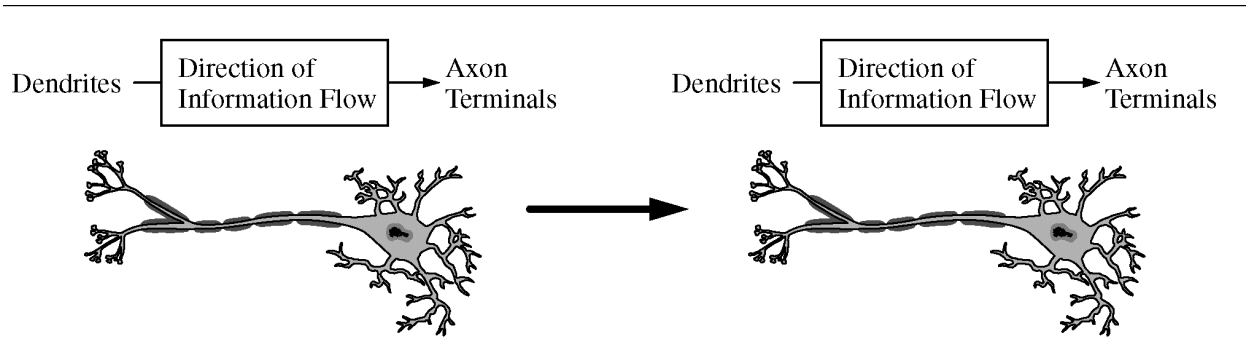
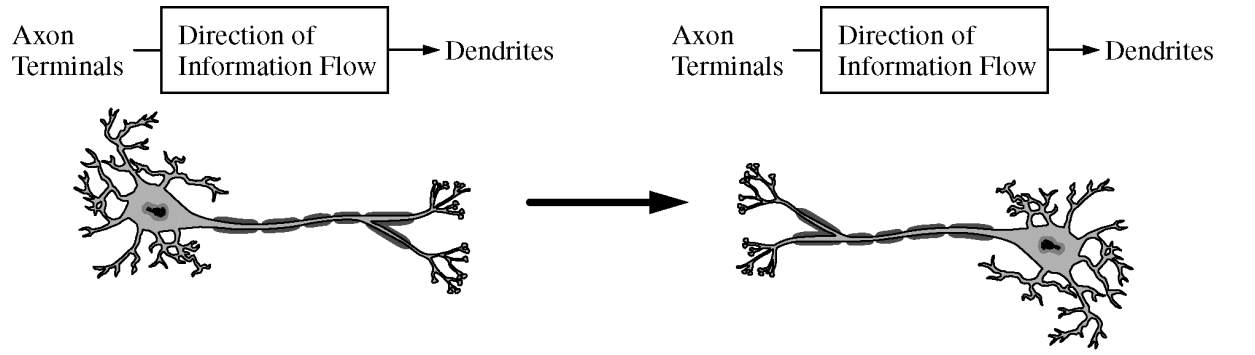
46. Information is transmitted through the nervous system when one neuron signals another neuron. The structure of neurons enables transmission to proceed quickly and efficiently. Which of the following diagrams correctly identifies both the structure of neurons and the direction of information flow between neurons?

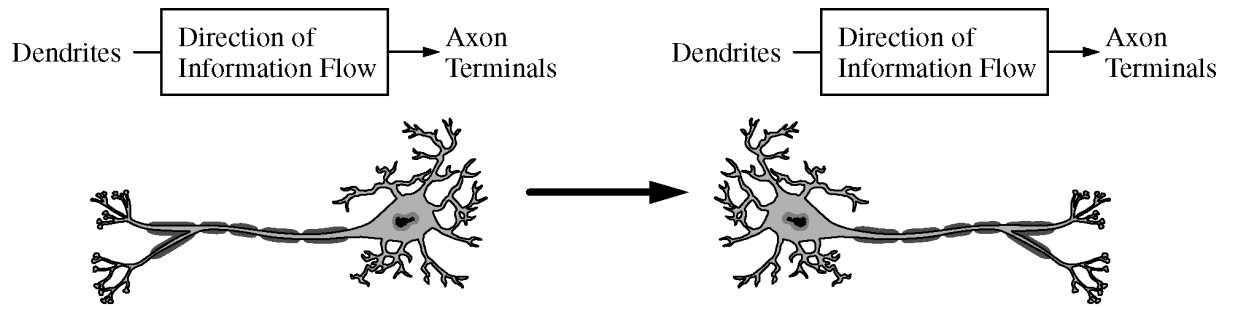
(A)



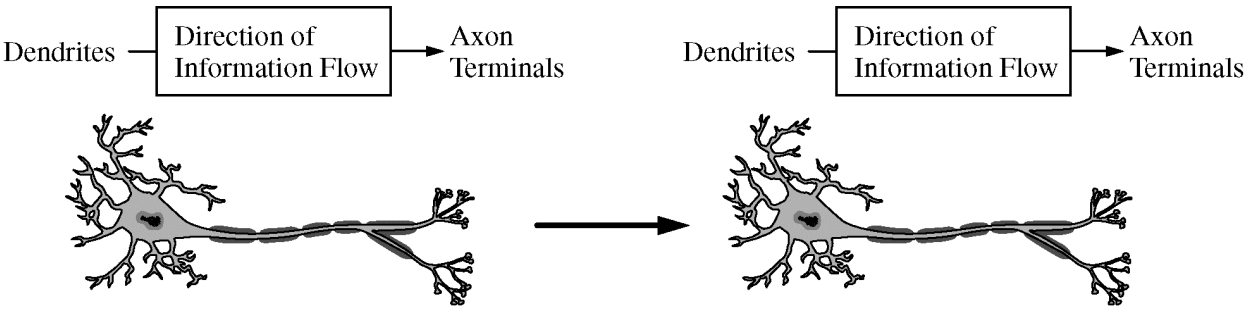
(B)



(C)



(D)



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47. A series of crosses is performed with fruit flies (*Drosophila melanogaster*) to examine inheritance of the genes *vestigial* (*vg*) and *cinnabar* (*cn*). The recessive *vg* allele causes small, malformed wings called vestigial wings. The recessive *cn* allele causes bright-red eyes called cinnabar eyes.

In the first cross, a female with wild-type wings and eyes is mated with a male with vestigial wings and cinnabar eyes. All the F_1 individuals have wild-type wings and eyes. In the second cross, female F_1 flies are mated with males with vestigial wings and cinnabar eyes. The phenotypes of 500 F_2 individuals are shown in the table.

Phenotype	Number of Individuals
Wild-type wings, wild-type eyes	226
Wild-type wings, cinnabar eyes	25
Vestigial wings, wild-type eyes	26
Vestigial wings, cinnabar eyes	223

Which of the following is the most likely explanation of the results?

(A) The two genes are located on two different chromosomes.
(B) The two genes are sex-linked.
(C) The two genes are located on mitochondrial DNA.
(D) The two genes are linked on an autosome.

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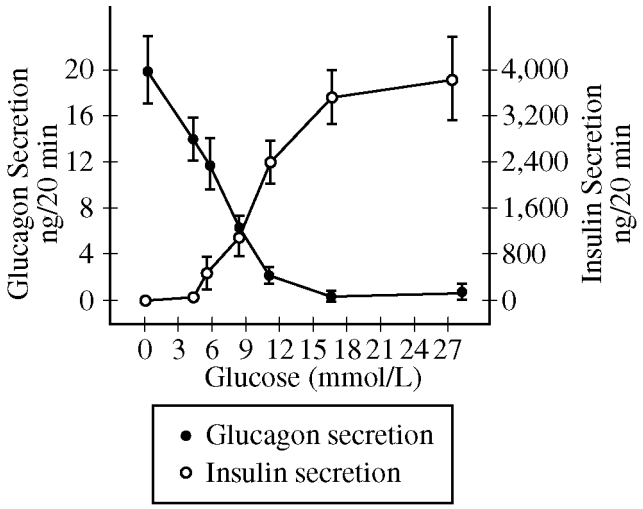

48. The graph above shows changes in glucagon and insulin secretions at different concentrations of blood glucose. Which of the following feedback mechanisms is best supported by the data?

(A) A falling glucagon level causes a rise in the insulin level, which maintains equal amounts of both hormones in the blood.
(B) A high glucagon level causes a rise in the insulin level, which maintains high levels of both hormones in the blood.
(C) A low glucose level causes the release of glucagon, which stimulates the release of more glucose from tissues, which in turn lowers the amount of glucagon being released.
(D) A low glucose level causes the release of insulin, which stimulates the release of more glucose from tissues, which in turn increases the amount of insulin being released.

49. Which of the following best describes an advantage that eukaryote organisms have over prokaryote organisms?

(A) Prokaryotes lack a cell membrane and therefore are unable to control what enters or exits the cell.
(B) Eukaryotes have a nuclear envelope separating their DNA from the rest of the cell, which increases the likelihood of advantageous mutations.
(C) Eukaryotes have mitochondria and chloroplasts that contain their own genome, which allows the cells to reproduce more rapidly.
(D) Eukaryotes have organelles that allow for compartmentalization of cellular processes, which increases the efficiency of those processes.

50. Gregor Mendel's pioneering genetic experiments with pea plants occurred before the discovery of the structure and function of chromosomes. Which of the following observations about inheritance in pea plants could be explained only after the discovery that genes may be linked on a chromosome?

(A) Pea color and pea shape display independent inheritance patterns.
(B) Offspring of a given cross show all possible combinations of traits in equal proportions.
(C) Most offspring of a given cross have a combination of traits that is identical to that of either one parent or the other.
(D) Recessive phenotypes can skip a generation, showing up only in the parental and F_2 generations.

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51. In animals, the *hox* genes encode a family of transcription factors that are important for proper development of embryonic segments and are widely conserved in organisms. The figure below shows the embryonic segments in which one such gene, *Hoxc6*, is expressed in the embryo of a mouse, a chick, and a goose. Embryonic segments are counted from the anterior end.

During the formation of vertebrae, the most anterior embryonic segment that expresses *Hoxc6* marks the end of the cervical (neck) vertebrae and the beginning of the thoracic (rib) vertebrae. All mammals have seven cervical vertebrae.

Which of the following statements is most likely to be true?

(A) The chick and the goose have the same number of thoracic vertebrae.
(B) The most anterior expression of *Hoxc6* is the eighth vertebra in mammals.
(C) *Hoxc6* is expressed in the same embryonic segments in birds and mammals.
(D) *Hoxc6* is expressed in the same vertebra at the anterior end of all bird embryos.

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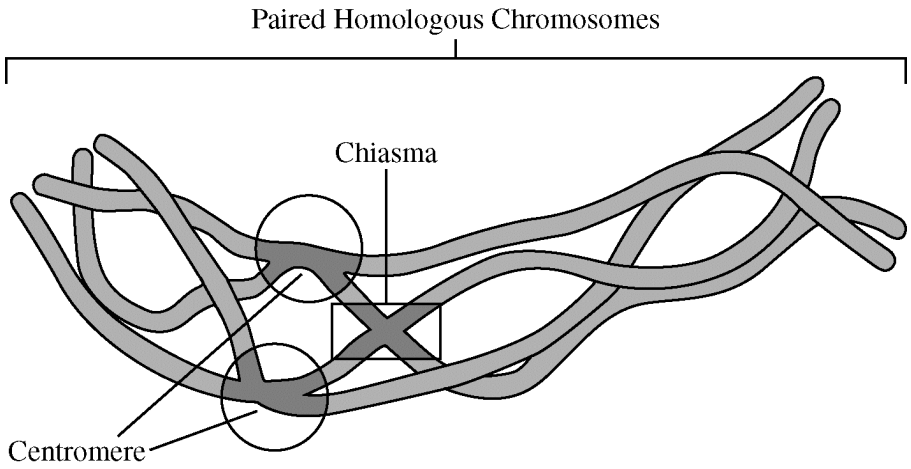


52. The process depicted in the image above is best summarized by which of the following descriptions?

(A) During the synthesis phase of the cell cycle, DNA molecules replicate to generate identical daughter cells.
(B) Centromeres align specific gene sequences of homologous chromosomes during mitotic divisions.
(C) The spindle apparatus attaches at chiasma during metaphase of mitosis.
(D) During meiosis, crossing over leads to recombination of alleles between homologous chromosomes.

53. A biologist is studying territoriality in three related species of birds found in the same section of a forest. For each observed pair of nesting adults, the biologist measured the distance to the next closest nesting pair of the same species (nearest-neighbor distance). An analysis of the results is shown in the table below.

Species	Mean Nearest-Neighbor Distance (km)	Median Nearest-Neighbor Distance (km)	Range of Nearest-Neighbor Distances (km)
I	0.35	0.47	0.25–0.50
II	0.31	0.32	0.30–0.32
III	0.80	1.10	0.10–1.50

Which of the following would be most appropriate for identifying the species with the most even distribution of nests?

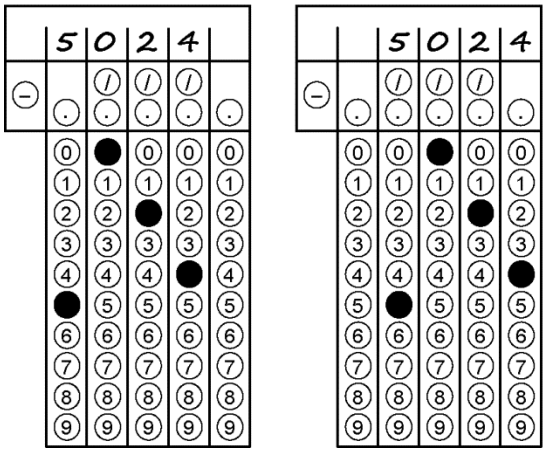
(A) Area of the forest in which the nearest-neighbor measurements were made
(B) Total number of nearest-neighbor observations collected during the study period
(C) Standard deviation of the nearest-neighbor distances for each species
(D) Proportion of nearest-neighbor distances that were less than the median

GO ON TO THE NEXT PAGE.

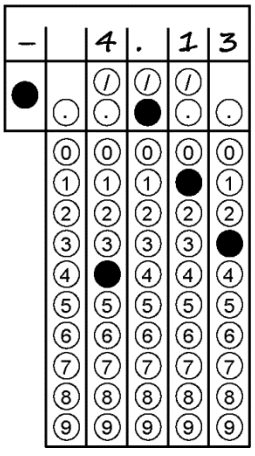
Directions: The next five questions, numbered 121–125, require numeric answers.
Determine the correct answer for each question and enter it in the grid on page 3 of the answer sheet.
Use the following guidelines for entering your answers.

- 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).

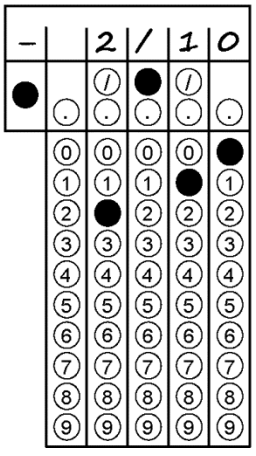
Integer answer: 5024
(either position is correct)



Decimal answer
−4.13



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



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121. Researchers observe a large population of birds on a remote island. Birds in the population are found to have either red crest feathers or white crest feathers on their heads. Genetic analysis indicates that the allele for red crest feathers is dominant over the allele for white crest feathers. In a survey of the population, the researchers determine the frequencies of the crest-feather phenotypes. The results of the survey are shown in the table below.

PHENOTYPE FREQUENCIES IN AN ISOLATED BIRD POPULATION	
Phenotype	Number of Individuals
Red crest feathers	11,088
White crest feathers	1,759

Assuming that the bird population is in Hardy-Weinberg equilibrium, what proportion of future populations is expected to be heterozygous for the allele controlling crest feather color? Give your answer as a value between 0 and 1, rounded to two decimal places.

122. A typical human lymphocyte has a radius of about 10 μm, while a typical bacterium (e.g., *S. pneumoniae*) has a radius of about 1 μm.

Assuming that both cell types are perfectly spherical, how many times larger is the surface area of a typical human lymphocyte compared to the surface area of a typical bacterium?

5′-ATGCGCGACGCGATTTGAC-3′

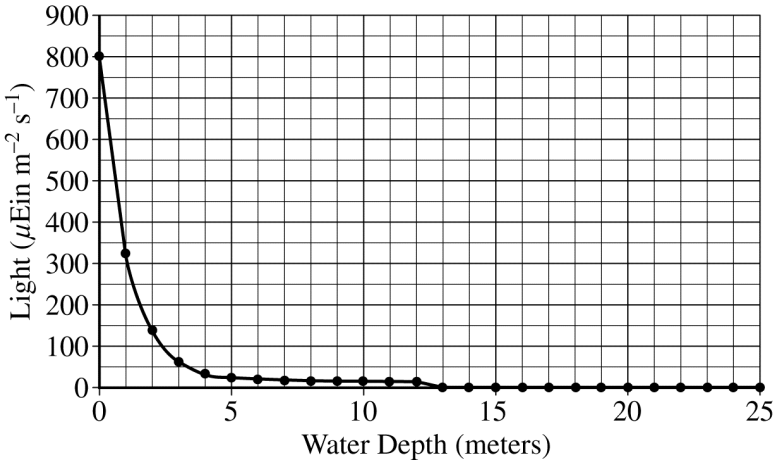
123. One method for predicting the average temperature (in ºC) at which a short DNA molecule binds with its complement is to calculate a melting temperature (T_m) using the following formula.

$$T_m = 4\ (G + C) + 2\ (A + T)$$

Using the formula, what is the predicted T_m for the short single-stranded DNA molecule shown above?

GO ON TO THE NEXT PAGE.

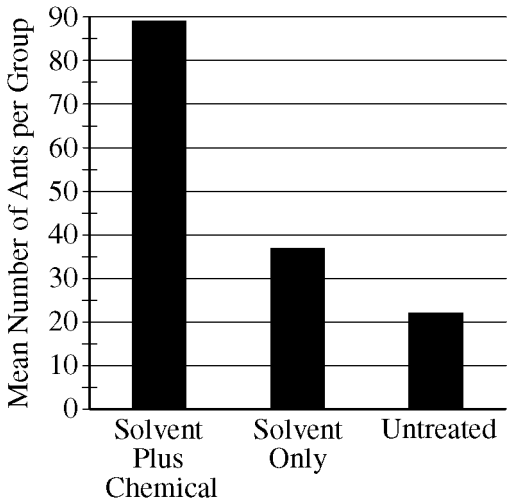
124. As part of a study to observe the activity of photosynthetic organisms in a temperate-zone lake, measurements of light penetration were made at different water depths. The results are presented in the graph below. Note that higher light-penetration values indicate a greater amount of light reaching the water at that depth.



According to the data above, what is the deepest water level at which light penetration is expected to be at least 200 μEin m^{-2} s^{-1}? Give your answer to the nearest tenth of a meter.

GO ON TO THE NEXT PAGE.

125. An experiment on plant defenses was conducted on three identical groups of lima bean plants. The first group was treated with a solution containing a chemical similar to an organic compound that is released by herbivore-damaged plants (solvent plus chemical). The second group was treated with only the solvent used in the first treatment. The third group was left untreated. One week after the treatment phase, the numbers of carnivorous ants (predators of herbivores) found residing on the plants in each group were determined. The results of the experiment are provided below.



Based on the information in the graph, how many times more ants are found on plants exposed to the solvent plus chemical compared to plants exposed to the solvent only? Give your answer to the nearest tenth.

GO ON TO THE NEXT PAGE.

S T O P

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 2014 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

2014

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

At a Glance

Total Time
1 hour, 30 minutes
Number of Questions
8
Percent of Total Score
50%
Writing Instrument
Pen with black or dark blue ink
Electronic Device
Four-function calculator (with square root)

Reading Period

Time
10 minutes. Use this time to read the questions and plan your answers.

Writing Period

Time
1 hour, 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. Do NOT begin writing on the lined pages until the proctor tells you to do so.

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.

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 (ºC + 273)

Surface Area and Volume

Volume of a Sphere

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

Volume of a Rectangular Solid

$$V = \ell w h$$

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

$A = \sum$ 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)

$$C_i V_i = C_f V_f$$

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

8 Questions

Planning Time—10 minutes

Writing Time—80 minutes

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. 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.

$$\text{Catechol} + \text{Oxygen} \xrightleftharpoons{\text{Polyphenol Oxidase}} \text{Benzoquinone} + \text{Water}$$

1. Catechol, a natural substance found in plants, reacts with oxygen to produce benzoquinone and water, as represented by the chemical equation above. The reaction is catalyzed in plants by the enzyme polyphenol oxidase. Accumulation of benzoquinone in plant tissue results in the gradual appearance of a brown color.

   A student observes that lemon juice (pH 2) slows the browning of apple slices. The student claims that lemon juice slows the browning process by altering the activity of polyphenol oxidase. To test the claim, the student distributes equal amounts of a dilute catechol solution to 6 identical test tubes. The pH of each solution was adjusted as shown in the table, and the initial absorbance was recorded. Equal amounts of polyphenol oxidase were added to each reaction tube. After 10 minutes at room temperature the absorbance of 389 nm light (A_{389}) was measured for each sample. Solutions containing greater concentrations of benzoquinone absorb more light. The changes in A_{389} are shown in the table below.

POLYPHENOL OXIDASE ACTIVITY

Test Tube	pH	Change in A_{389} After Incubation with Enzyme
A	1.0	0.06
B	3.0	0.09
C	5.0	0.23
D	7.0	0.83
E	9.0	0.32
F	11.0	0.10

   (a) On the axes provided, **construct** an appropriately labeled bar graph to analyze the effect of pH on polyphenol oxidase activity.

   (b) Based on the experimental results, **estimate** the optimal pH of the enzyme. **Explain** your estimate by connecting the experimental results to the structure and function of proteins.

   (c) **Propose** an appropriate control treatment for the experiment, and **describe** how the control treatment would increase the validity of the results.

   (d) Genetic engineering can be used to disrupt specific genes in the genome of an organism. **Predict** how the browning of apple slices would be affected in a strain of apples that was genetically engineered to lack functional copies of the gene encoding polyphenol oxidase. **Justify** your response.

GO ON TO THE NEXT PAGE.

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.

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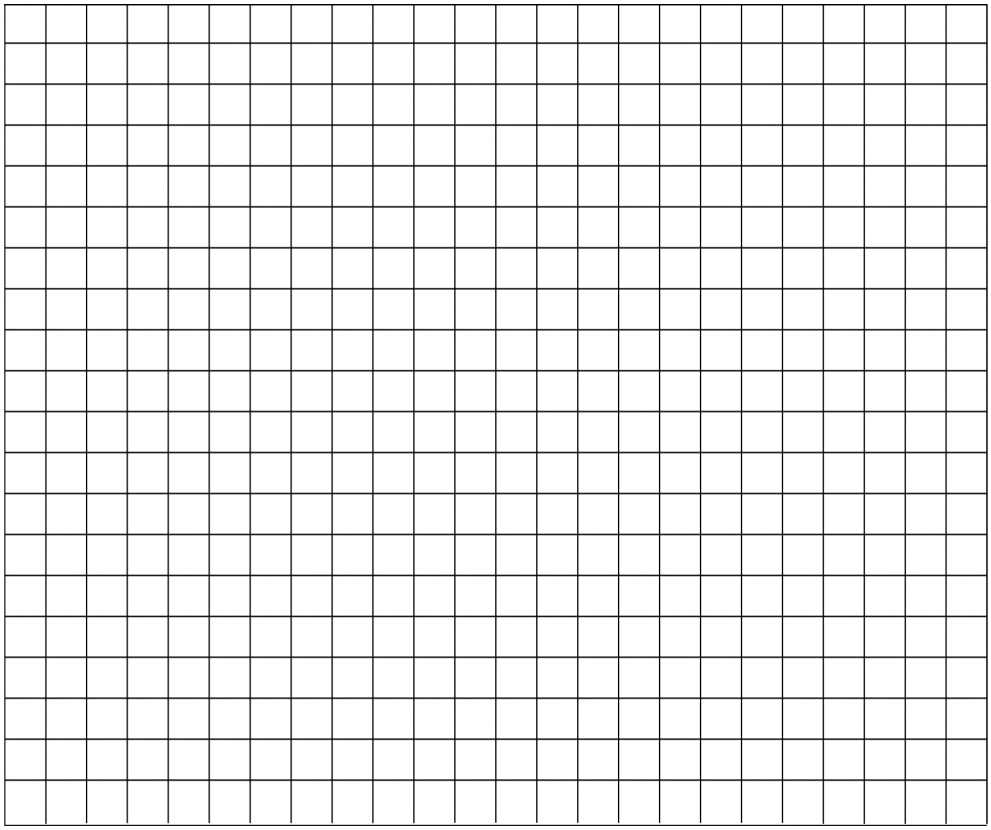
PAGE FOR ANSWERING QUESTION 1



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ADDITIONAL PAGE FOR ANSWERING QUESTION 1

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ADDITIONAL PAGE FOR ANSWERING QUESTION 1

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ADDITIONAL PAGE FOR ANSWERING QUESTION 1

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2. Loeys-Dietz syndrome (type 2B) is a human genetic disorder associated with mutations in the *LDS2B* gene. Researchers have proposed that the *LDS2B* gene produces a growth factor receptor protein that regulates cell signaling pathways. The predicted product of the gene is a 565-amino acid protein with structural regions that bind to signaling molecules, span the plasma membrane, and have protein kinase activity. Protein kinases are cellular enzymes that transfer phosphate groups from ATP to target proteins. A representation of the *LDS2B* gene is shown in Figure 1.

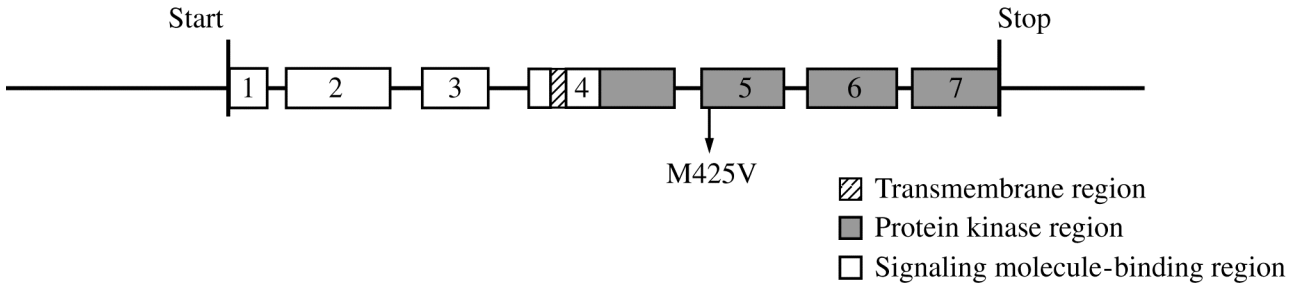

Figure 1. Genomic structure of the *LDS2B* gene. The seven exons (numbered rectangular boxes), the introns (thin lines between the boxes), and the start and stop signals for translation are represented. The portions of the gene that encode the different structural regions of the protein are shown, and the location of a methionine-to-valine substitution at position 425 of the encoded polypeptide (M425V) is indicated.

Second Base in Codon

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

Figure 2. Universal Codon Table

(a) Based on a pedigree of a family in which one parent in the first generation has Loeys-Dietz syndrome (type 2B), a researcher claims that the disorder is an autosomal dominant condition. **Describe** TWO characteristics of the pedigree that would support the researcher's claim.

(b) **Calculate** the minimum number of nucleotides required in the coding region of the *LDS2B* mRNA molecule to produce and terminate the 565-amino acid polypeptide. **Provide** TWO reasons that the number of nucleotides in the mature mRNA may differ from the number of base pairs in the gene.

(c) One genetic change associated with the disorder results in a methionine-to-valine substitution at amino acid position 425 of the encoded polypeptide, as shown in Figure 1. Using the codon table in Figure 2, **predict** a DNA point mutation that will result in a methionine-to-valine substitution.

(d) **Propose** THREE features of a model to connect the genetic mutation you predicted with the activity of a signaling pathway involving the *LDS2B* gene product.

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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.

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PAGE FOR ANSWERING QUESTION 2

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ADDITIONAL PAGE FOR ANSWERING QUESTION 2

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ADDITIONAL PAGE FOR ANSWERING QUESTION 2

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ADDITIONAL PAGE FOR ANSWERING QUESTION 2

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AMINO ACID AT POSITION 104 OF β-HEMOGLOBIN

Species	Amino Acid 104
Horse	Arginine (Arg)
Gorilla	Lysine (Lys)
Chimpanzee	Arginine (Arg)
Human	Arginine (Arg)

3. β-hemoglobin is a highly conserved protein among vertebrates. The identity of amino acid 104–one of the variable amino acids in the polypeptide–in four vertebrate species is shown in the table above.

   A student constructed the phylogenetic tree shown in Figure 1 by comparing the amino acid sequences of β-hemoglobin in the four species. The student placed "Lys" at an incorrect position on the phylogenetic tree in an attempt to show when the mutation affecting amino acid 104 occurred.

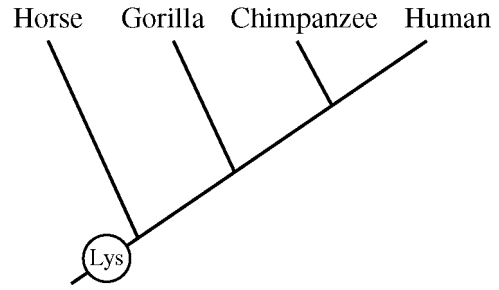


Figure 1. Student-constructed Phylogenetic Tree of Vertebrate Species with Incorrect Placement of "Lys"

Second Base in Codon

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

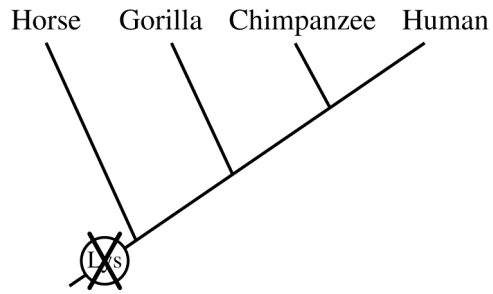
Figure 2. Codon Table

GO ON TO THE NEXT PAGE.

(a) **Refine** the student's model by placing "Lys" at the correct position on the phylogenetic tree to indicate where the Arg-to-Lys mutation most likely occurred. **Provide** ONE piece of reasoning to support your placement of "Lys" on the phylogenetic tree.

(b) **Predict** the most likely single mutation affecting amino acid 104 in the species and **justify** how β-hemoglobin can function normally in all four species despite the mutation.

PAGE FOR ANSWERING QUESTION 3



Part (a): Refinement of Student Model

4. Bacteria and fungi are found in all ecosystems on Earth. A scientist claims that fungi are keystone species in a particular terrestrial ecosystem. To test this hypothesis, the scientist divides an area within the ecosystem into multiple small plots of similar size. Equal numbers of plots are then randomly assigned to one of three treatment groups. Plots in the first group are sprayed with a water-soluble substance that selectively kills fungi. Plots in the second group are sprayed with a water-soluble substance that selectively kills bacteria. Plots in the third group are sprayed with the same volume of water only. After a certain period of time, the scientist then measures the amount of accessible nutrients in the soil in each plot.

   (a) **Describe** ONE common role of both bacteria and fungi in the movement of energy and matter in ecosystems.

   (b) **Describe** how analyzing the data from the treatment group sprayed with water only will increase the validity of the experimental results.

   (c) Based on the scientist's claim, **predict** which treatment group will have the smallest amount of accessible nutrients in the soil at the end of the experiment. **Justify** your prediction in terms of the relative impact of a keystone species in the environment.

PAGE FOR ANSWERING QUESTION 4

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ADDITIONAL PAGE FOR ANSWERING QUESTION 4

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5. Tetrodotoxin (TTX) is a neurotoxin that blocks the Na^+ channels of the neuronal membrane. The puffer fish, which contains TTX in its liver, is considered a delicacy in Japan even though eating incorrectly prepared puffer fish can be fatal to humans.

   (a) **Describe** TWO functions of neurotransmitters at the postsynaptic membrane.

   (b) Based on the information provided above, **explain** how TTX most likely interferes with the transmission of information across synapses.

PAGE FOR ANSWERING QUESTION 5

ADDITIONAL PAGE FOR ANSWERING QUESTION 5

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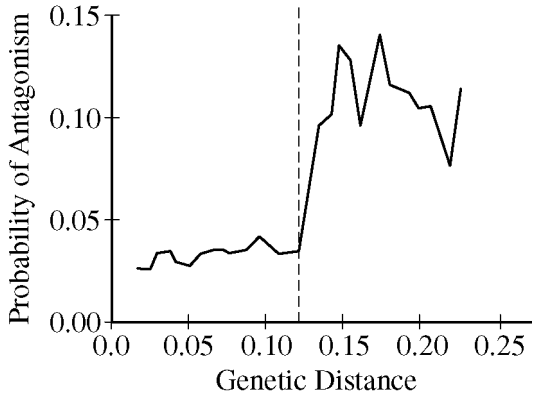

6. In a study of bacterial communities, researchers investigated interactions among naturally occurring strains of *Vibrio* bacteria. The researchers found that some *Vibrio* bacteria secrete antimicrobial substances that inhibit the growth and reproduction of other bacteria (antagonism). The researchers also found that some strains of *Vibrio* bacteria produce no antimicrobial substances themselves but instead live in close proximity to other bacteria that produce antimicrobial substances to which they are not susceptible (cooperation).

   By testing approximately 35,000 pairs of naturally occurring strains of *Vibrio* bacteria, the researchers identified 830 antagonistic interactions among genetically related *Vibrio* strains. The graph represents the probability of antagonism between any two given strains of *Vibrio* bacteria as a function of genetic relatedness (genetic distance). The greater the genetic distance, the less related are any two bacterial strains.

   (a) **Describe** ONE type of molecular evidence that can be used to determine the genetic relatedness of bacterial strains isolated from naturally occurring populations.

   (b) Using the information presented in the graph, **describe** the relationship between antagonism and genetic relatedness in the communities of *Vibrio* bacteria sampled for the study.

   (c) **Provide** reasoning to show how the results of the study support the claim that cooperation among *Vibrio* bacteria can increase the fitness of some individual bacteria living in a natural environment.

PAGE FOR ANSWERING QUESTION 6

ADDITIONAL PAGE FOR ANSWERING QUESTION 6

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7. According to the chemiosmotic model proposed by Peter Mitchell in 1961, an electrochemical gradient is linked to the synthesis of ATP in mitochondria. Construct an explanation of the chemiosmotic model by doing each of the following.

   (a) **Make** a claim about the role of the inner mitochondrial membrane in ATP synthesis.

   (b) **Present** ONE piece of evidence that supports the role you proposed in part (a).

   (c) **Provide** reasoning to explain how the evidence you presented in part (b) supports the claim you made in part (a).

PAGE FOR ANSWERING QUESTION 7

ADDITIONAL PAGE FOR ANSWERING QUESTION 7

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8. In 1952 Alfred Hershey and Martha Chase used radioactive phosphorus and radioactive sulfur to selectively label the DNA and proteins of bacteriophage T2, a virus that infects bacteria. After incubating the labeled bacteriophage particles with *Escherichia coli* and separating extracellular phage particles from the bacteria, Hershey and Chase measured the amounts of radioactive phosphorus and sulfur inside infected *E. coli* cells and in the liquid growth medium outside the *E. coli* cells.

   (a) **Predict** the experimental result that would best support the claim that DNA is the source of heritable information, and **provide** reasoning to explain how the result supports the claim.

   (b) Bacteriophages, like other viruses, consist primarily of a protein coat and packaged DNA. **Describe** the function of ONE critical enzyme in bacterial cells that is necessary for replicating bacteriophage DNA.

PAGE FOR ANSWERING QUESTION 8

ADDITIONAL PAGE FOR ANSWERING QUESTION 8

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S T O P

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 Answer Key

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

Answer Key for AP Biology Practice Exam, Section I

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

Question 121: $0.46 \leq x \leq 0.48$, $46/100 \leq x \leq 48/100$

Question 122: 100, 100/1

Question 123: 60, 60/1

Question 124: $1.2 \leq x \leq 1.8$, $12/10 \leq x \leq 18/10$

Question 125: $2.2 \leq x \leq 2.6$, $22/10 \leq x \leq 26/10$

Free-Response Scoring Guidelines

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

AP® BIOLOGY
2014 SCORING GUIDELINES

Question 1

$$\text{Catechol} + \text{Oxygen} \xrightleftharpoons{\text{Polyphenol Oxidase}} \text{Benzoquinone} + \text{Water}$$

Catechol, a natural substance found in plants, reacts with oxygen to produce benzoquinone and water as represented by the chemical equation above. The reaction is catalyzed in plants by the enzyme polyphenol oxidase. Accumulation of benzoquinone in plant tissue results in the gradual appearance of a brown color.

A student observes that lemon juice (pH 2) slows the browning of apple slices. The student claims that lemon juice slows the browning process by altering the activity of polyphenol oxidase. To test the claim, the student distributes equal amounts of a dilute catechol solution to 6 identical test tubes. The pH of each solution was adjusted as shown in the table and the initial absorbance was recorded. Equal amounts of polyphenol oxidase were added to each reaction tube. After 10 minutes at room temperature the absorbance of 389-nm (A_{389}) light was measured for each sample. Solutions containing greater concentrations of benzoquinone absorb more light. The changes in A_{389} are shown in the table below.

Test Tube	pH	Change in A_{389} After Incubation with Enzyme
A	1.0	0.06
B	3.0	0.09
C	5.0	0.23
D	7.0	0.83
E	9.0	0.32
F	11.0	0.10

(a) On the axes provided, **construct** an appropriately labeled bar graph to analyze the effect of pH on polyphenol oxidase activity. (**3 points maximum**; LO 2.9, 4.17)

- Axes correctly labeled
- Axes correctly scaled
- Data correctly plotted as a bar graph with pH as the independent variable

AP® BIOLOGY
2014 SCORING GUIDELINES

Question 1 (continued)

(b) Based on the experimental results, **estimate** the optimal pH of the enzyme. **Explain** your estimate by connecting the experimental results to the structure and function of proteins. (**3 points maximum**; LO 4.22, 4.17, 4.14)

Estimated (**1 point**)
- Optimal pH of enzyme is 7 OR greater than 5 and less than 9

Explanation (**2 points maximum**)	
Evidence (**1 point**)	• Reaction at the optimal pH value has the highest absorbance/ amount of product produced • Other pH values had lower absorbance/produce less product
Justification (**1 point**)	A change in pH... • alters the structure of the enzyme's active site and reduces its • alters the charge of R-groups and reduces the enzyme's activity • disrupts substrate binding and/or catalytic mechanism and reduces • denatures the enzyme and reduces its activity

(c) **Propose** an appropriate control treatment for the experiment, and **describe** how the control treatment would increase the validity of the results. (**2 points maximum**; LO2.22, 2.23)

NOTE: Points are earned in a single row only.

Control Treatment (**1 point**)	Description (**1 point**)
Reaction without enzyme	Confirms enzyme is necessary.
Reaction with denatured enzyme	Confirms active enzyme is necessary.
Reaction under anaerobic conditions (no oxygen)	Confirms oxygen is necessary.
Reaction without catechol	Confirms catechol is necessary.

d) Genetic engineering can be used to disrupt specific genes in the genome of an organism. **Predict** how the browning of apple slices would be affected in a strain of apples that was genetically engineered to lack functional copies of the gene encoding polyphenol oxidase. **Justify** your response. (**2 point**; LO 3.24, 3.5)

NOTE: Points are earned in a single row only.

Prediction (**1 point**)	Justification (**1 point**)
Fruit will not brown	• Browning requires a functional enzyme.
Fruit will brown more slowly	• The reaction occurs spontaneously but more slowly without enzyme. • Enzyme reduces activation energy.

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2014 SCORING GUIDELINES

Question 2

Loeys-Dietz syndrome (type 2B) is a human genetic disorder associated with mutations in the *LDS2B* gene. Researchers have proposed that the *LDS2B* gene produces a growth factor receptor protein that regulates cell signaling pathways. The predicted product of the gene is a 565-amino acid protein with structural regions that bind to signaling molecules, span the plasma membrane, and have protein kinase activity. Protein kinases are cellular enzymes that transfer phosphate groups from ATP to target proteins. A representation of the *LDS2B* gene is shown in Figure 1.

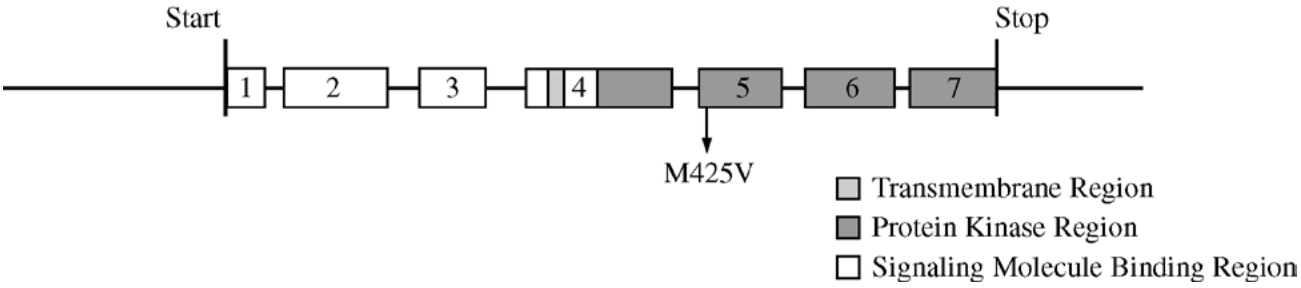

Figure 1. Genomic structure of the *LDS2B* gene. The seven exons (numbered rectangular boxes), the introns (thin lines between the boxes), and the start and stop signals for translation are represented. The portions of the gene that encode the different structural regions of the protein are shown, and the location of a methionine-to-valine substitution at position 425 of the encoded polypeptide (M425V) is indicated.

Second Base in Codon

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

Figure 2. Universal Codon Table

Question 2 (continued)

(a) Based on a pedigree of a family in which one parent in the first generation has Loeys-Dietz syndrome (type 2B), a researcher claims that the disorder is an autosomal dominant condition. **Describe** TWO characteristics of the pedigree that would support the researcher's claim. (**2 points maximum**; LO3.12, 3.17)

Evidence to support autosomal inheritance (**1 point**)	Evidence to support dominant inheritance (**1 point**)
• Inherited equally by males and females • Both males and females have equal chance of transmitting the trait	• Phenotype is most likely observed in each generation. • If the trait is not observed in one generation it will not be observed in subsequent generations. • There are no unaffected carriers of the allele. • Each affected individual must have one or more affected parent.

(b) **Calculate** the minimum number of nucleotides required in the coding region of the *LDS2B* mRNA molecule to produce and terminate the 565-amino acid polypeptide. **Provide** TWO reasons that the number of nucleotides in the mature mRNA may differ from the number of base pairs in the gene. (**4 points maximum**; LO 3.1, 3.4, 4.5)

Result of Calculation (**2 points**)

NOTE: Points are earned in one column only.

1695 (**1 point**)	1698 (**2 points**)	1701 (**2 points**)
Scoring Rationale		
• Response demonstrates understanding of triplet code in production of polypeptide. (565 amino acids × 3 nucleotides = 1695)	• Response demonstrates understanding of triplet code in production of polypeptide. • Response demonstrates understanding of the role of the stop codon in terminating translation. (1695 + 3 = 1698)	• Response demonstrates understanding of triplet code in production of polypeptide. • Response demonstrates understanding of the role of the start and stop codons in production of polypeptides from which the initial methionione is excised. (1695 + 3 + 3 = 1701)

Question 2 (continued)

Reasoning (**2 points**)

- RNA is modified or processed.
- Introns are removed from mRNA but remain in the gene structure.
- 5' cap adds a nucleotide that is not encoded by the gene.
- PolyA tail adds nucleotides to the 3' end of the mRNA that are not encoded by the gene.
- The gene has regulatory sequences (promoters/enhancers) that are not transcribed.
- Alternative splicing mixes different exons

(c) One genetic change associated with the disorder results in a methionine-to-valine substitution at amino acid position 425 of the encoded polypeptide, as shown in Figure 1. Using the codon table in Figure 2, predict a DNA point mutation that will result in a methionine-to-valine substitution. (**1 point maximum**; LO 4.3)

- A → G OR AUG → GUG (from the codon table)
- T → C
- A/T → G/C

(d) **Propose** THREE features of a model to connect the genetic mutation you predicted with the activity of a signaling pathway involving the *LDS2B* gene product. (**3 points maximum**; LO 2.28, 3.25, 4.9, 3.36)

- Mutation causes a structural change in polypeptide.
- Change in sequence activates signaling (a gain of function).
- Change in sequence decreases signaling pathway (a loss of function).
- An altered protein could change other components of the signaling pathway (downstream effect).
    - Buildup or loss of ATP
    - Increase or decrease of phosphorylated proteins
    - An effect on the overall cascade
    - Buildup or decrease of signal molecule
    - Interferes with the growth factor/affects growth

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Question 3

AMINO ACID AT POSITION 104 OF β-HEMOGLOBIN

Species	Amino Acid 104
Horse	Arginine (Arg)
Gorilla	Lysine (Lys)
Chimpanzee	Arginine (Arg)
Human	Arginine (Arg)

β-hemoglobin is a highly conserved protein among vertebrates. The identity of amino acid 104–one of the variable amino acids in the polypeptide–in four vertebrate species is shown in the table above.

A student constructed the phylogenetic tree shown in Figure 1 by comparing the amino acid sequences of β-hemoglobin in the four species. The student placed "Lys" at an incorrect position on the phylogenetic tree in an attempt to show when the mutation affecting amino acid 104 occurred.

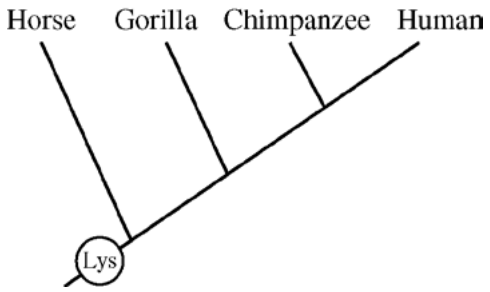

Figure 1. Student-constructed Phylogenetic Tree of Vertebrate Species with Incorrect Placement of Lys

Second Base in Codon

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

Figure 2. Codon Table

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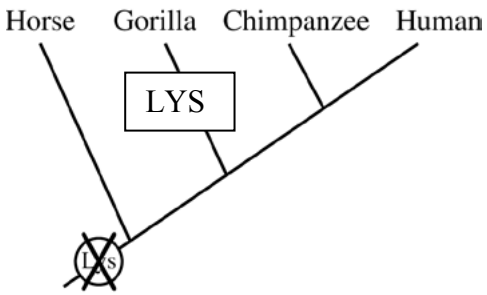
Question 3 (continued)

(a) **Refine** the student's model by placing "Lys" at the correct position on the phylogenetic tree to indicate where the Arg-to-Lys mutation most likely occurred. **Provide** ONE piece of reasoning to support your placement of "Lys" on the phylogenetic tree. (**2 points maximum**; LO 1.10)

Refinement (**1 point**)

- Correctly places "lys" on branch leading to Gorilla



Part (a): Refinement of Student Model

Reasoning (**1 point**)

- Gorillas are the only species in the clade with "lys."
- The mutation could only have occurred in the branch that uniquely leads to the gorillas.
- If the mutation occurred on the main branch before the gorilla line, then the chimp and human lines would also be affected.

(b) **Predict** the most likely single mutation affecting amino acid 104 in the species and **justify** how β-hemoglobin can function normally in all four species despite the mutation.
(**2 points maximum**; LO 1.18, 4.3)

Prediction (**1 point**)

- G → A mutation in second position of the Arg codon of the coding/nontemplate strand
- C →T in second position of the Arg codon of the non-coding/template strand
- G/C → A/T mutation in second position of the Arg codon

Justification (**1 point**)

- If the substitution doesn't cause a major disruption of structure, the function is maintained.
- Conservative substitutions (amino acids having similar R-groups) are less likely to disrupt structure/function.

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Question 4

Bacteria and fungi are found in all ecosystems on Earth. A scientist claims that fungi are keystone species in a particular terrestrial ecosystem. To test this hypothesis, the scientist divides an area within the ecosystem into multiple small plots of similar size. Equal numbers of plots are then randomly assigned to one of three treatment groups. Plots in the first group are sprayed with a water-soluble substance that selectively kills fungi. Plots in the second group are sprayed with a water-soluble substance that selectively kills bacteria. Plots in the third group are sprayed with the same volume of water only. After a certain period of time, the scientist then measures the amount of accessible nutrients in the soil in each plot.

(a) **Describe** ONE common role of both bacteria and fungi in the movement of energy and matter in ecosystems. (**1 point**; LO4.27)

- Both bacteria and fungi recycle nutrients by breaking down organic matter.
- Both bacteria and fungi break down dead and decaying matter as their primary energy source.

(b) **Describe** how analyzing the data from the treatment group sprayed with water only will increase the validity of the experimental results. (**1 point**; LO2.22, 4.11, 4.19)

- Describe that the water only treatment is a control that allows any change in the experimental groups to be attributed to the presence or absence of bacteria or fungi.

(c) Based on the scientist's claim, **predict** which treatment group will have the smallest amount of accessible nutrients in the soil at the end of the experiment. **Justify** your prediction in terms of the relative impact of a keystone species in the environment. (**2 points maximum**; LO4.27, 4.11)

Prediction (**1 point**)	Justification (**1 point**)
The Group 1 treatment will result in the smallest amount of accessible nutrients in the soil at the end of the experiment.	Keystone species have a disproportionate impact on the ecosystem relative to their abundance.

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Question 5

Tetrodotoxin (TTX) is a neurotoxin that blocks the Na^+ channels of the neuronal membrane. The puffer fish, which contains TTX in its liver, is considered a delicacy in Japan even though eating incorrectly prepared puffer fish can be fatal to humans.

(a) **Describe** TWO functions of neurotransmitters at the postsynaptic membrane. (**2 points maximum**; LO 3.45)

- Neurotransmitters bind to receptor molecules.
- Neurotransmitters open ion channels.
- Neurotransmitters change membrane potential/ allow depolarization to occur/generate an action potential.

(b) Based on the information provided above, **explain** how TTX most likely interferes with the transmission of information across synapses. (**2 points maximum**; LO 3.39, 2.28, 3.43)

NOTE: Points are earned in a single row only.

Evidence (1 point)	Reasoning (1 point)
No action potential in neurons	Na^+ cannot flow across neuronal membranes
No reaction in postsynaptic cell	• No Ca^{++} released to trigger migration or fusion of vesicles containing neurotransmitters • No neurotransmitter released

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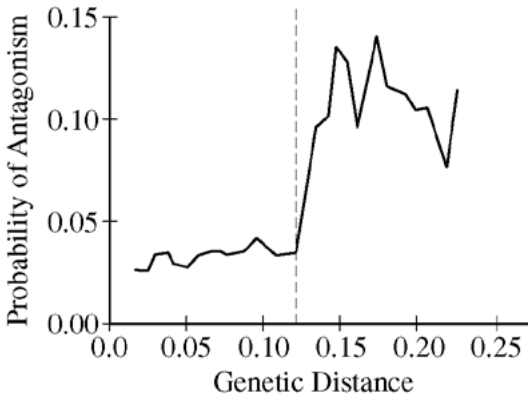
Question 6



In a study of bacterial communities, researchers investigated interactions among naturally occurring strains of *Vibrio* bacteria. The researchers found that some *Vibrio* bacteria secrete antimicrobial substances that inhibit the growth and reproduction of other bacteria (antagonism). The researchers also found that some strains of *Vibrio* bacteria produce no antimicrobial substances themselves but instead live in close proximity to other bacteria that produce antimicrobial substances to which they are not susceptible (cooperation).

By testing approximately 35,000 pairs of naturally occurring strains of *Vibrio* bacteria, the researchers identified 830 antagonistic interactions among genetically related *Vibrio* strains. The graph represents the probability of antagonism between any two given strains of *Vibrio* bacteria as a function of genetic relatedness (genetic distance). The greater the genetic distance, the less related are any two bacterial strains. (**3 points maximum**)

(a) **Describe** ONE type of molecular evidence that can be used to determine the genetic relatedness of bacterial strains isolated from naturally occurring populations. (**1 point**; LO 1.9)

Description may include:

- DNA sequence comparison between the two bacterial strains
- RNA sequence comparison between the two bacterial strains
- Protein sequence comparison between the two bacterial strains
- Biochemical strategies comparison
- Components of ribosomes comparison

(b) Using the information presented in the graph, **describe** the relationship between antagonism and genetic relatedness in the communities of *Vibrio* bacteria sampled for the study. (**1 point**; LO 4.12)

Description may include:

- ↓ genetic distance ↓ antagonism
- ↑ genetic relatedness ↓ antagonism
- ↑ genetic distance ↑ antagonism
- ↓ genetic relatedness ↑ antagonism
- There is a threshold of genetic relatedness beyond which probability of antagonism increases sharply

Question 6 (continued)

(c) **Provide** reasoning to show how the results of the study support the claim that cooperation among *Vibrio* bacteria can increase the fitness of some individual bacteria living in a natural environment. (**1 point**; LO 4.19)

- By producing antimicrobial substances, the bacteria inhibit the growth of strains that are genetically unrelated.
- By producing antimicrobial substances, the bacteria promote the growth of bacteria that are genetically related.
- Individuals who do not produce antimicrobial substances but are genetically related to those who do gain a selective advantage due to reduced competition/decreased energy expenditure.

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Question 7

According to the chemiosmotic model proposed by Peter Mitchell in 1961, an electrochemical gradient is linked to the synthesis of ATP in mitochondria. Construct an explanation of the chemiosmotic model by doing each of the following.

(a) **Make** a claim about the role of the inner mitochondrial membrane in ATP synthesis.
(**1point maximum**; LO 2.5, 2.13)

(b) **Present** ONE piece of experimental evidence that supports the role you proposed in part (a).
(**1 point maximum**; LO 2.5, 2.13)

(c) **Provide** reasoning to explain how the evidence you presented in part (b) supports the claim you made in part (a).
(**1 point maximum**; LO 2.5, 2.13)

NOTE: Points are earned in a single row only.

(a) Claim (**1point**)	(b) Evidence (**1 point**)	(c) Reasoning (**1 point**)
IMM maintains a proton gradient required for ATP synthesis.	• The pH of the intermembrane space is lower than the pH of the mitochondrial matrix • ATP can be produced by incubating isolated mitochondria with low pH buffer and ADP + P_i • Membrane is not permeable to hydrogen ions	• pH is a measure of proton concentration; higher proton concentration --> lower pH
	• Protonophores/uncouplers dissipate the proton gradient and prevent ATP synthesis • Proton gradient has sufficient energy to drive ATP synthesis.	• Protons move through ATP synthase from intermembrane space to matrix and produce ATP
• Electron transport chain is in IMM and creates a proton gradient • Electron transport chain is in IMM and leads to ATP synthesis	• $NADH/FADH_2$ are oxidized by electron carriers and electrons move through complex finally reducing O_2 to H_2O. • ETC results in most ATP in cellular respiration. • Proton gradient has sufficient energy to drive ATP synthesis. • Protons accumulate across the membrane • ATP can be produced by incubating isolated mitochondria with low pH buffer and ADP + P_i	• Energy from oxidizing $NADH/FADH_2$ is converted to energy in proton gradient (PMF) energy in gradient can be coupled to ATP synthesis • Protons move through ATP synthase from intermembrane space to matrix and produce ATP
IMM is the site for ATP synthesis	• Presence of ATP synthase in IMM • IMM is where ADP undergoes phosphorylation • IMM contains ATP synthase complex for making ATP.	• Protons move through ATP synthase from intermembrane space to matrix and produce ATP

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Question 8

In 1952 Alfred Hershey and Martha Chase used radioactive phosphorus and radioactive sulfur to selectively label the DNA and proteins of bacteriophage T2, a virus that infects bacteria. After incubating the labeled bacteriophage particles with *Escherichia coli* and separating extracellular phage particles from the bacteria, Hershey and Chase measured the amounts of radioactive phosphorus and sulfur inside infected *E. coli* cells and in the liquid growth medium outside the *E. coli* cells.

(a) **Predict** the experimental result that would best support the claim that DNA is the source of heritable information, and **provide** reasoning to explain how the result supports the claim. (**2 points maximum**; LO3.1, 3.2)

Prediction **(1 point)**

- Radioactive phosphorus label is found mostly inside infected cells.
- Radioactive sulfur label is found mostly in the growth media/not inside the cells.

Reasoning **(1 point)**

- Radioactive phosphorus labels DNA.
- Radioactive sulfur does not label DNA.
- Radioactive sulfur primarily labels proteins.
- Presence of radioactive phosphorus inside cell supports DNA as hereditary information.

(b) Bacteriophages, like other viruses, consist primarily of a protein coat and packaged DNA. **Describe** the function of ONE critical enzyme in bacterial cells that is necessary for replicating bacteriophage DNA. (**1 point maximum**; LO3.3)

- DNA polymerase synthesizes new DNA.
- Helicase and/or topoisomerases unwind parental DNA.
- Ligase joins Okazaki fragments.

Scoring Worksheet

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

2014 AP Biology Scoring Worksheet

Section I: Multiple Choice

_____	× 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
92-120	5
72-91	4
52-71	3
31-51	2
0-30	1

AP Biology

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