CollegeBoard

# AP® Biology Practice Exam

## From the 2016 Administration

**NOTE:** This is a modified version of the 2016 AP Biology Exam.

# Contents



Note: This publication shows the page numbers that appeared in the *2015–16 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 *2015–16 AP Exam Instructions* book.

# AP® Biology Exam

Regularly Scheduled Exam Date: Monday morning, May 9, 2016
Late-Testing Exam Date: Friday afternoon, May 20, 2016
Section I Total Time: 1 hr. 30 min. Section II Total Time: 1 hr. 30 min.

**Section I**

**Total Time:** 1 hour 30 minutes
**Number of Questions:** 69*
(63 multiple-choice questions plus 6 grid-in questions; 1 hour 30 minutes)
**Percent of Total Score:** 50%
**Writing Instrument:** Pencil required

**The number of questions may vary slightly depending on the form of the exam.*

**Section II**

**Total Time:** 1 hour 30 minutes
**Number of Questions:** 8 questions
(2 ten-point questions, 3 four-point questions, and 3 three-point questions, 10-minute reading period, 1 hour 20-minute writing period)
**Percent of Total Score:** 50%
**Writing Instrument:** Pen with black or dark blue ink

**Note**: Four-function calculators (with square root) may be used on all sections of the AP Biology Exam.

**What Proctors Need to Bring to This Exam**

- Exam packets
- Answer sheets
- AP Student Packs
- *2015-16 AP Coordinator's Manual*
- This book — *AP Exam Instructions*
- AP Exam Seating Chart template(s)
- School Code and Home-School/Self-Study Codes
- Extra calculators
- Pencil sharpener
- Container for students' electronic devices (if needed)
- Extra No. 2 pencils with erasers
- Extra pens with black or dark blue ink
- Lined paper
- Stapler
- Watch
- Signs for the door to the testing room
  - "Exam in Progress"
  - "Cell phones are prohibited 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 44–47 of the *2015-16 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 45 of the *2015-16 AP Coordinator's Manual*. Students may have no more than two calculators on their desks. Calculators may not be shared.

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

Make sure you begin the exam at the designated time. Remember, you must complete a seating chart for this exam. See pages 305–306 for a seating chart template and instructions. See the *2015-16 AP Coordinator's Manual* for exam seating requirements (pages 49–52).

*If you are giving the regularly scheduled exam, say:*

**It is Monday morning, May 9, 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 20, 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 *2015-16 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 can still 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 of your exam booklet 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. For the multiple-choice questions, the answer sheet has circles marked A–E for each question. For Biology, you will use only the circles marked A–D. You must complete the answer sheet using a No. 2 pencil only. Open your answer sheet to page 2. Mark all of your responses beginning on page 2 of your answer sheet, one response per question. No credit will be given for anything written in the exam booklet. Scratch paper is not allowed, but you may use the margins or any blank space in the exam booklet for scratch work. If you need to erase, do so carefully and completely. Your score on the multiple-choice section will be based solely on the number of questions answered correctly. Four-function calculators (with square root) are allowed.**

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

**in correctly. Please pay close attention to the directions in your exam booklet for completing the grid-in questions.**

**Are there any questions? . . .**

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

Note Start Time 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 20 minutes, say:

**There are 10 minutes remaining.**

After 10 minutes, say:

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

Collect an answer sheet from each student. Check that each answer sheet has an AP number label and an AP Exam label. After all answer sheets have been collected, say:

**Now you must seal your exam booklet using the white seals you set aside earlier. Remove the white seals from the backing and press one on each area of your exam booklet cover marked "PLACE SEAL HERE." Fold each seal over the back cover. When you have finished, place the booklet on your desk, 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. All items you placed under your chair at the beginning of this exam must stay there, and you are not permitted to open or access them in any way. Leave your shrinkwrapped Section II packet on your desk during the break. You are not allowed to consult teachers, other students, notes, or textbooks during the break. You may not make phone calls, send text messages, use your calculators, check email, use a social networking site, or access any electronic or communication device. Remember, you may never discuss the multiple-choice questions at any time in any form with anyone, including your teacher and other students. If you disclose these questions through any means, your AP Exam score will be canceled. Are there any questions? . . .**

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

## SECTION II: Free Response

After the break, say:

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

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

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

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

**Read the last statement. . . .**

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

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

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

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

**Read Item 4. . . .**

**Are there any questions? . . .**

**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. . . .**

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

Collect the Student Packs. Then say:

**Are there any questions? . . .**

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

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

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

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

Note Start Time here _____. Note Stop Time here _____. After 10 minutes, say:

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

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 a question in the free-response section, have those students staple the extra sheet(s) to the first page corresponding to that question in their exam booklets. Complete an Incident Report. A single Incident Report may be completed for multiple students per exam subject per administration (regular or late testing) as long as all of the required information is provided. Include all exam booklets with extra sheets of paper in an Incident Report return envelope (see page 60 of the *2015-16 AP Coordinator's Manual* for complete details). Then say:

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

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

- Exam booklet front cover: The student placed an AP number label on the shaded box and printed 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 Exam 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 Exam score results will be available online in July.**

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

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

Then say:

**You are now dismissed.**

All exam materials must be placed 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 *2015-16 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.

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

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

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

# AP Answer Sheet 2016

**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 *2015-16 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**

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

**O. 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.

785208

**SCHOOL USE ONLY**

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

Fee Reduction Granted: 1 Option 1 2 Option 2

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Q4068/1-4

**COMPLETE THIS AREA AT EACH EXAM (IF APPLICABLE).**

**P. 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 |

**Q. 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 for Questions 1 through 120. 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 |

**ETS USE ONLY**

| | | |
|---|---|---|
| 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 |

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

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 |

## QUESTIONS 121–126

**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

## QUESTIONS 131–142

**For Students Taking AP Physics 1 or AP Physics 2**

**Mark two responses per question. You will receive credit only if both correct responses are selected.**

| | | | | | |
|---|---|---|---|---|---|
| 131 | A B C D | 135 | A B C D | 139 | A B C D |
| 132 | A B C D | 136 | A B C D | 140 | A B C D |
| 133 | A B C D | 137 | A B C D | 141 | A B C D |
| 134 | A B C D | 138 | A B C D | 142 | A B C D |



DO NOT WRITE IN THIS AREA

## COMPLETE THIS AREA ONLY ONCE.

**R. 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 | MS | OR | WV | |
| AZ | IL | MT | PA | WY | |
| CA | IN | NC | RI | Puerto Rico | |
| CO | KS | ND | SC | | |
| CT | KY | NE | SD | AA | |
| DC | LA | NH | TN | AE | |
| DE | MA | NJ | TX | AP | |
| FL | MD | NM | UT | Other | |
| GA | ME | NV | VA | | |

**V. SEX**

- Female
- Male

**W. WHICH LANGUAGE DO YOU KNOW BEST?**

- English
- English and another language about the same
- Another language

**X. RACIAL/ETHNIC GROUP**

Please answer both questions about Hispanic origin and about race. For the following questions about your identity, Hispanic origins are not races.

(You may mark all that apply.)

**a. Are you of Hispanic, Latino, or Spanish origin?**

- No, not of Hispanic, Latino, or Spanish origin
- Yes, Cuban
- Yes, Mexican
- Yes, Puerto Rican
- Yes, another Hispanic, Latino, or Spanish origin

**b. What is your race?**

- American Indian or Alaska Native
- Asian (including Indian subcontinent and Philippines origin)
- Black or African American (including Africa and Afro-Caribbean origin)
- Native Hawaiian or other Pacific Islander
- White (including Middle Eastern origin)

**Y. PARENTAL EDUCATION LEVEL**

In the first column, indicate the highest level of education of one parent/guardian, and indicate whether this is your mother/female guardian or father/male guardian. Then, if applicable, indicate the highest level of education of your other parent/guardian in the second column, and indicate whether this is your mother/female guardian or father/male guardian.

| | |
|---|---|
| **Mother or female guardian** | |
| **Father or male guardian** | |
| Grade school | |
| Some high school | |
| High school diploma or equivalent | |
| Vocational 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 | |

**S. FOR STUDENTS OUTSIDE THE UNITED STATES ONLY** If your address does not fit in the spaces provided in Item R, fill in as many circles as you can, then fill in the circle in Item S and print the remainder of your address in the spaces provided.

**T. STUDENT IDENTIFIER** (Student ID Number)

| Address | City | State or Province | Country | ZIP or Postal Code |
|---|---|---|---|---|
| | | | | |

**U. 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 *2015-16 Bulletin for AP Students and Parents*.

# Section I:
# Multiple-Choice and Grid-In Questions

This is the multiple-choice and grid-in section of the 2016 AP exam.
It includes cover material and other administrative instructions
to help familiarize students with the mechanics of the exam.
(Note that future exams may differ in look from the following content.)

For purposes of test security and/or statistical analysis, some questions
have been removed from the version of the exam that was administered
in 2016. Therefore, the timing indicated here may not be appropriate
for a practice exam.

# AP® Biology Exam

## SECTION I: Multiple Choice and Grid-In

2016

**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<br>(A) state<br>(B) city<br>(C) country<br>(D) continent | Ⓐ ● Ⓒ Ⓓ Ⓔ |

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

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

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

**Form I**
**Form Code 4MBP4-S**

# AP® BIOLOGY EQUATIONS AND FORMULAS

## Statistical Analysis and Probability

**Mean**

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

**Standard Deviation**

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

**Standard Error of the Mean**

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

**Chi-Square**

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

**Chi-Square Table**

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

**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

$\bar{x}$ = 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.

**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 | $\mu$ |
| $10^{-9}$ | 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 ($\Psi$)**

$$\Psi = \Psi_P + \Psi_S$$

$\Psi_P$ = pressure potential

$\Psi_S$ = 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**

$A = \Sigma$ surface area of each side

$r$ = radius

$\ell$ = length

$h$ = height

$w$ = width

$s$ = length of one side of a cube

$A$ = surface area

$V$ = volume

$\Sigma$ = 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**

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

$\Delta G$ = change in Gibbs free energy

$\Delta S$ = change in entropy

$\Delta H$ = 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. Two populations of a species of squirrel are geographically isolated from each other. Although they have the same population density, one population is significantly larger in number than the other. A new bacterial disease, which is easily spread and extremely virulent, affects both populations at the same time.

   Which of the following is the best prediction of how the new disease will affect the two populations?

   (A) The two populations will be equally affected, because the ability to trigger an immune response is randomly distributed among all squirrels of that species.
   (B) The larger population will be less affected by the disease than will the smaller population, because the mutation rate of the larger population is higher than the mutation rate of the smaller population.
   (C) The smaller population will be more affected than will the larger population, because the smaller population has less genetic variation than the larger population has.
   (D) The smaller population will be less affected than will the larger population, because the smaller population exhibits more genetic drift than the larger population exhibits.

2. Mitochondria are found in most eukaryotic cells and contain their own DNA and ribosomes that are similar to those typical of many prokaryotic cells. Which of the following statements is justified by these observations?

   (A) The mitochondrion is the only location in which eukaryotic cells can synthesize ATP.
   (B) An ancestral cell most likely engulfed an aerobic prokaryote in a relationship that proved beneficial for both cells.
   (C) Mitochondrial membranes provide abundant surface area for reactions because of the infoldings called cristae.
   (D) The mitochondrion plays a role in respiration, but it also stores the cell's extra mRNA.



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3. Sickle-cell anemia is associated with a mutation in the gene encoding the beta subunit of hemoglobin that results in a change from glutamic acid to valine at position 6. All other amino acids are identical to a normal hemoglobin molecule.

   Based on the information above, which of the following mutations is the most likely cause of sickle-cell anemia?

   (A) A single base-pair substitution in the gene encoding the beta subunit
   (B) A single base-pair insertion in the gene encoding the beta subunit
   (C) A single base-pair deletion in the gene encoding the beta subunit
   (D) A translocation of DNA from one chromosome to another

4. In the year 2000, specimens of *Caulerpa taxifolia*, a green alga used in tropical aquariums, were found off the coast of California. Native to the Indian Ocean, *C. taxifolia* is known for aggressive growth and an ability to compete with sea grasses. It is currently on an international list of invasive species. Which of the following best predicts the consequences of the introduction of *C. taxifolia* to the California coast?

   (A) Without natural herbivores or competitors, *C. taxifolia* will grow rapidly and crowd out native species of producers.
   (B) *C. taxifolia* will have a hard time establishing itself because it will have to compete against native species of sea grasses, which are better adapted to the environment.
   (C) *C. taxifolia* will grow rapidly, leading to an increase in the diversity of producers.
   (D) Because it is not in the Indian Ocean, its natural environment, *C. taxifolia* will not be able to grow efficiently.



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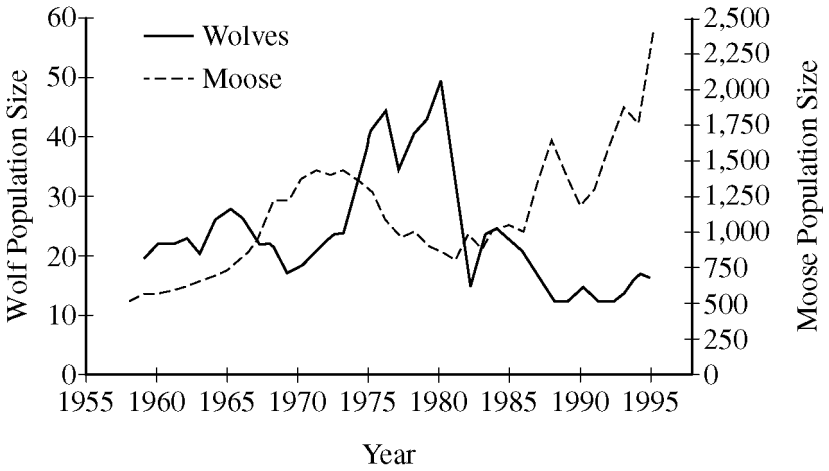


5. The graph above represents the number of individuals in a population of wolves and in a population of moose observed in the same isolated geographic area over a 40-year period, from 1955 through 1995. Which of the following statements about the two populations is best supported by the information presented in the graph?

   (A) The reproductive rate of the wolves was greater than the reproductive rate of the moose.
   (B) Mutualism allowed the two populations to reproduce while occupying the same ecological niche.
   (C) Speciation occurred when the two populations became reproductively isolated from each other.
   (D) The wolves were predators of the moose, which were otherwise reproductively successful.



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**Questions 6-9**

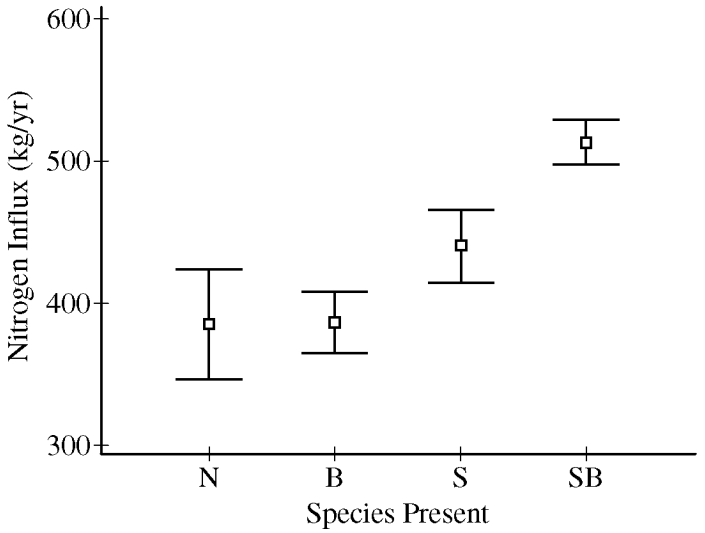


Figure 1. Mean nitrogen influx $\pm 2SE_{\bar{X}}$ as a function of species present. N = neither salmon nor bears present, B = only bears present, S = only salmon present, and SB = both salmon and bears present.

Pacific salmon and black bears have often been cited as examples of keystone species. Pacific salmon spawn in freshwater streams but spend most of their lives at sea. When mature salmon return to the freshwater streams to spawn, they are preyed upon by bears and other predators. When salmon migrate from their marine habitat to the freshwater streams, they bring nitrogen and other marine-derived nutrients that subsequently remain in the areas surrounding the streams—a process called nitrogen influx.

In an investigation, the relationship between black bears, salmon, and influx of marine nitrogen into the area around a southwestern Alaskan stream was studied. The investigators established several test plots of the same size along the stream with the following species composition: no salmon or black bears (N), bears but not salmon (B), salmon but not bears (S), and a plot where salmon and bears interact (SB). Nitrogen influx in the different sampling areas was measured as a means of assessing the impact of the different species on the health of the ecosystem. The data are plotted in Figure 1.



GO ON TO THE NEXT PAGE.

6. Which of the following statements is best supported by the data?

   (A) Black bears are a keystone species.
   (B) Salmon are a keystone species.
   (C) Black bear urine is a significant source of nitrogen in the environment.
   (D) The presence of black bears and salmon correlates with a significant increase in nitrogen influx.

7. Which of the following most likely describes how the interaction between bears and salmon influences nitrogen dynamics in the environment?

   (A) When bears consume salmon, they leave parts of the carcasses on the ground, which decompose, releasing nitrogen into the environment.
   (B) When salmon swim upstream to spawn, bears migrate to the rivers and deposit nitrogen from the forest with their excrement.
   (C) Bears are a reservoir for nitrogen because they are the top consumer in the environment.
   (D) Bears urinate in rivers and streams, which provides nitrogen for the salmon.

8. Which of the following pieces of additional data would help further investigate the relationship between bears, salmon, and influx of nitrogen into the local environment?

   (A) The experimenters should remove the remains of salmon carcasses immediately after the salmon are eaten by the bears and determine the nitrogen content of the carcasses.
   (B) The experimenters should increase the number of bears in the area and measure the amount of nitrogen available for uptake by plants.
   (C) The experimenters should set up a net to catch salmon before they enter the area and then measure nitrogen influx.
   (D) The experimenters should clear-cut the trees from the area and determine how much nitrogen remains in the streams.

9. If a dam is built downstream and prevents salmon migration to the test sites, which of the following most accurately predicts the impact on nitrogen influx?

   (A) Nitrogen influx will increase because the bears will no longer store nitrogen from the salmon.
   (B) Nitrogen influx will decrease because there will be less bear-salmon interaction.
   (C) Nitrogen influx will remain stable because organisms other than bears and salmon will mobilize nitrogen in the environment.
   (D) Nitrogen influx will increase because bears will no longer lose nitrogen to the salmon.



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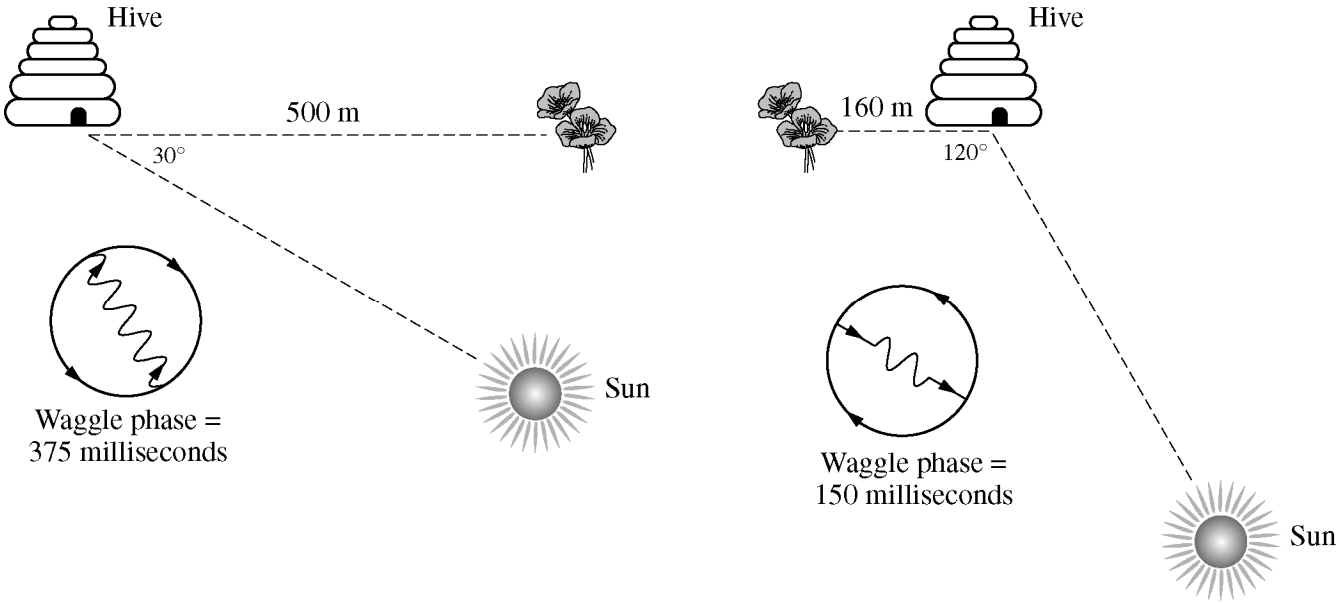


10. As depicted in the diagram, honeybees communicate the location of flower patches to members of their hives with waggle dances that give information about the direction and distance to the flowers. Which of the following statements about how honeybees communicate the position of flower patches is most consistent with the model?

(A) The number of repetitions of the waggle dance indicates the quality of the pollen source.
(B) The total area covered by any waggle dance leads bees to the target flowers.
(C) The angle of the waggle phase relative to the vertical plane indicates the position of the target flowers relative to another beehive.
(D) The farther the target flowers from the hive, the longer the waggle phase.



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11. Eye pigment in a particular strain of fly is determined by two genes. An autosomal gene that controls the color of the pigments in the eye has two alleles: a dominant allele (*R*) that results in red eyes and a recessive allele (*r*) that results in sepia eyes. A sex-linked gene that controls the expression of the colored pigments also has two alleles: a dominant allele (*T*) that allows for expression of the colored pigments and a recessive allele (*t*) that does not allow for expression of the colored pigments. Individuals without a *T* allele have white eyes regardless of the alleles of other eye-color genes.

    Which of the following represents a cross between a white-eyed female and a red-eyed male?

    (A) $Tt\ X^RX^R \times tt\ X^rY$
    (B) $Tt\ X^rX^r \times tt\ X^RY$
    (C) $RR\ X^TX^T \times Rr\ X^TY$
    (D) $Rr\ X^tX^t \times Rr\ X^TY$

12. Some strains of the bacterium *Streptococcus pyogenes* secrete poisonous substances called exotoxins. The genes encoding the exotoxins are thought to have originated in bacteriophages, which are viruses that infect bacteria.

    Which of the following is the most likely mechanism by which the *S. pyogenes* acquired the ability to produce the exotoxins?

    (A) Bacteriophages engulfed cellular debris from dead bacteria.
    (B) Bacteriophages in the environment activated bacterial cell division.
    (C) Bacteriophage DNA became integrated in the bacterial chromosome.
    (D) Bacteriophage proteins were absorbed into bacteria cells by endocytosis.



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**Questions 13-16**

Over many generations, two populations of the same species can diverge into separate species through reproductive isolation. The figures below represent a model of speciation and show the results of matings between individuals from two diverging populations at four different stages of speciation. The males represented in the model are heterogametic, which means they have two different sex-determining chromosomes, (e.g., XY). The females are homogametic, which means they have two similar sex-determining chromosomes, (e.g., XX). The offspring from each mating are labeled interpopulation hybrids.

Figure 1 shows the results of a mating between a male and a female from the two populations. In each subsequent figure, the males are from one of the diverging populations and the females are from the other population. The fertility and viability of the offspring from each mating are indicated in the figures.

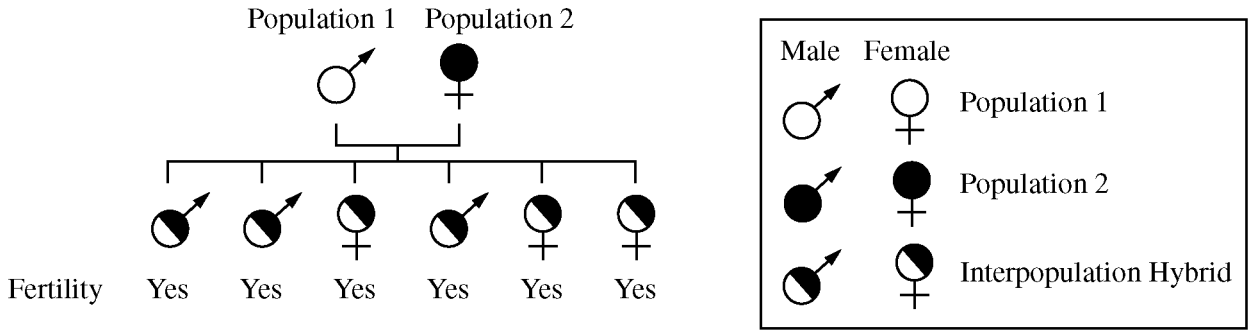


Figure 1. Mating between individuals from the initial populations

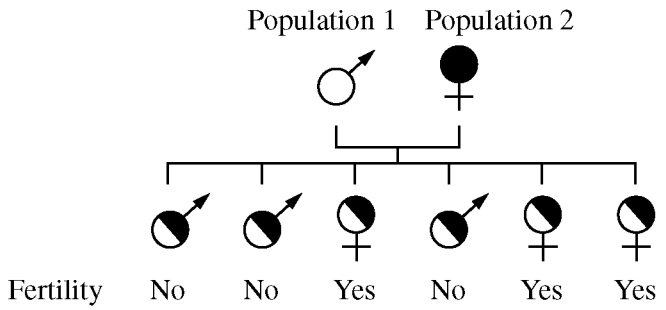


Figure 2. Mating between individuals from diverging populations at an intermediate stage of speciation

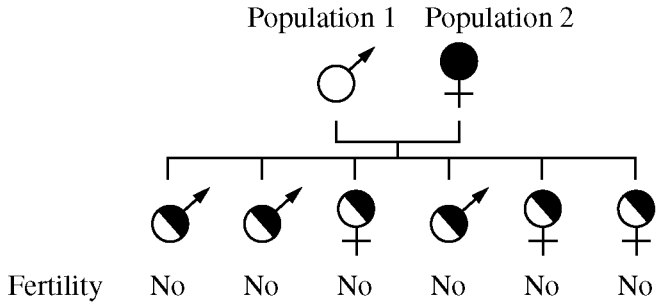


Figure 3. Mating between individuals from diverging populations at a late stage of speciation

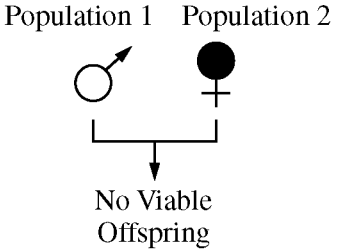


Figure 4. Mating between individuals from divergent populations after speciation is complete

13. Based on the model of speciation presented, which of the following describes the most likely consequence to the populations over time?

    (A) Hybrid individuals are less likely to pass their genetic information on to subsequent generations.
    (B) Hybrid individuals living together are physically unable to mate with each other.
    (C) Geographically isolated populations gradually acquire similar heritable traits.
    (D) Differences between hybrid individuals of a species disappear over time.

14. Which of the following best describes the reason for excluding hybrid males when calculating the allele frequencies of two interbreeding populations at the intermediate stage of speciation (Figure 2) ?

    (A) The process of mate selection in large groups often favors females over males.
    (B) The frequency of sex-determining chromosomes is usually equal to 0.5.
    (C) Sterile individuals make no genetic contribution to the next generation.
    (D) The chance of inheriting a recessive allele from a male is too small to calculate.

15. In a separate investigation, individual mice from two populations that in nature are geographically isolated from each other are mated in the laboratory. The hybrid offspring were then mated with individuals from either of the original populations. Only the female hybrid offspring were fertile. The experimental results are most consistent with which of the stages that are depicted in the model?

    (A) Initial population (Figure 1)
    (B) Intermediate stage (Figure 2)
    (C) Late stage (Figure 3)
    (D) Terminal stage (Figure 4)

16. Using the model of speciation and applying it to a different population, which of the following outcomes is most consistent for a different species in which the males are homogametic and the females are heterogametic?

    (A) Sterility would appear in females before appearing in males.
    (B) Speciation would occur more rapidly because females would produce more offspring.
    (C) Behavioral isolation would occur sooner in species exhibiting nonrandom mating.
    (D) The population would reach Hardy-Weinberg equilibrium at an accelerated rate.



GO ON TO THE NEXT PAGE.

17. A scientist is evaluating a proposal for raising large numbers of fish in ocean pens for human consumption. As part of the evaluation, the scientist is designing a plan for investigating how the fish in the ocean pens might affect nearby ecosystems.

    Which of the following is the most appropriate factor to use as the dependent variable in the experimental investigation?

    (A) The amount of metabolic wastes in the water where the fish are being raised
    (B) The water temperature in the natural habitat of the fish being studied
    (C) The types of fish that are preferentially consumed by humans
    (D) The amount of time it takes for fish to digest a meal

18. Epinephrine is a protein hormone found in many animals. Epinephrine stimulates a signaling pathway that results in the breakdown of glycogen to glucose in the liver cells. Which of the following describes the initial steps in the process whereby epinephrine stimulates glycogen breakdown?

    (A) Epinephrine binds to a cell-surface receptor; the activated receptor stimulates production of the second messenger, cAMP.
    (B) Epinephrine binds to a cell-surface receptor; the activated receptor catalyzes the conversion of glycogen to glucose.
    (C) Epinephrine diffuses through the plasma membrane; the hormone dimerizes in the cytosol.
    (D) Epinephrine is taken into the cell by endocytosis; glycogen is converted to glucose in the endocytotic vesicle.



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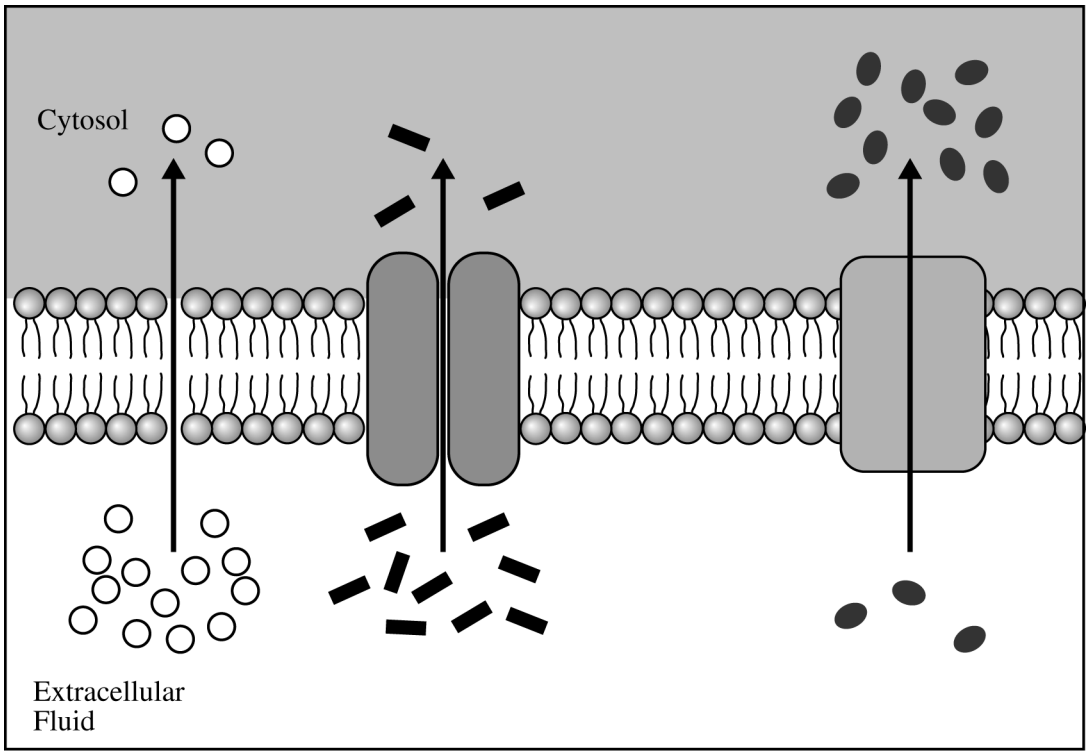



19. Which of the following scientific questions is most relevant to the model represented in the figure above?

(A) Is ATP required for the transportation of sugars across the outer mitochondrial membrane?
(B) Do the types of phospholipids in a membrane affect the rate at which molecules enter a cell by passive diffusion?
(C) Which molecular substance is actively transported across the plasma membrane?
(D) How does temperature affect the movement of molecules into lysosomes?



GO ON TO THE NEXT PAGE.

20. A group of students designed an experiment to determine the effect of compost on the germination and growth of plants. The students set up experimental plots by mixing different ratios of soil and compost. They planted 20 pea and 20 melon seeds in each plot and watered each plot regularly. The students recorded the number of seeds that germinated, and as the plants grew, they recorded plant length, number and size of leaves, and general health observations.

    The following observations were recorded.

    - In all treatments, more pea seeds germinated than melon seeds.
    - There was a week of rainy weather at three weeks.
    - Melon plants developed a fungal growth at four weeks.
    - Melon plants grew longer than pea plants, but many melon leaves showed signs of yellowing as the weeks passed.

    The students concluded that pea plants grew better in compost than did melon plants.

    Which of the following best addresses the validity of the conclusion made by the students?

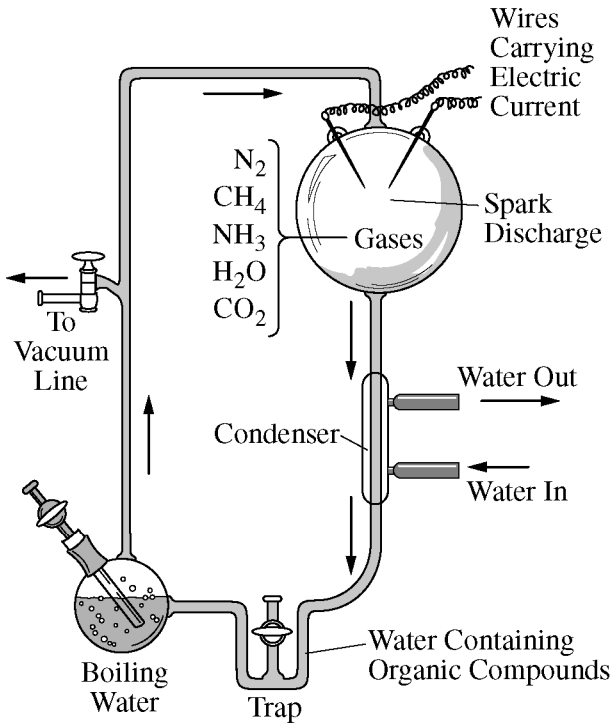
    (A) The conclusion is valid because the independent and dependent variables in the experiment were controlled.
    (B) The conclusion is valid because the experimental design included a large sample size.
    (C) The conclusion is invalid because other variables in the experiment (both biotic and abiotic) affected the results.
    (D) The conclusion is invalid because the units of measurement were not given in the experimental design.

21. Butterflies of the genus *Colias* live in the Rocky Mountains, where they experience a wide range of temperatures. Different variants of a particular glycolytic enzyme in the flight muscles are optimally active at different temperatures. Within the same population, some individual butterflies fly most effectively at 29°C, while others fly most effectively at 40°C. Still others can be equally active at both temperatures.

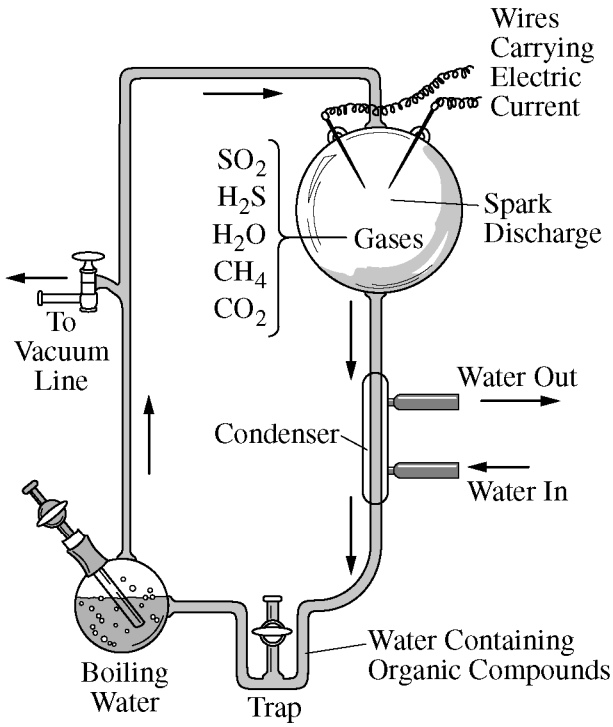
Which of the following claims is most consistent with the observed butterfly behavior?

(A) Butterflies that express two variants of the enzyme are active over a greater range of temperature.
(B) Butterflies that are active over a wide range of temperatures produce greater amounts of the enzyme.
(C) Temperature has little effect on the activity of butterflies.
(D) Butterflies that are active at warmer temperatures produce more offspring.

22. Two groups of students attempted to re-create the primitive atmospheric conditions of early Earth using the apparatus represented below. Each group ran the experiment with different gas mixtures in the apparatus.




Experiment 1




Experiment 2

Which of the following statements best justifies the claim that the conditions in at least one of the experiments could generate the molecular building blocks essential for life?

(A) The carbon dioxide ($CO_2$) gas and water ($H_2O$) vapor in experiment 1 could react spontaneously to produce the phospholipids required by the first life-forms.

(B) The nitrogen ($N_2$) gas and ammonia ($NH_3$) gas in experiment 1 could provide the elemental nitrogen required for the formation of amino acids.

(C) The sulfur dioxide ($SO_2$) gas in experiment 2 could donate the excited electrons required to drive the process of photosynthesis.

(D) The methane ($CH_4$) gas in experiment 2 could act as the electron acceptor required to complete the process of cellular respiration.



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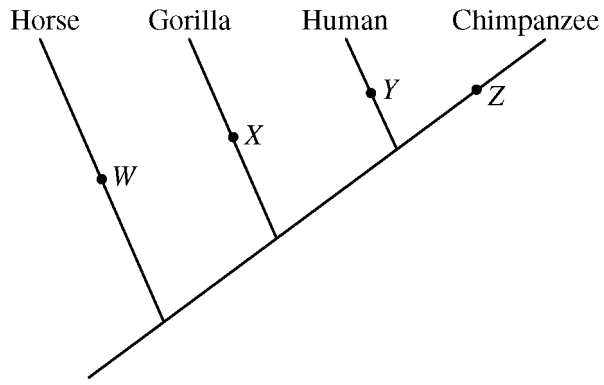
23. The cladogram shown below depicts an accepted model of the evolutionary relationships among selected species.




The amino acid at position 104 in the beta-hemoglobin protein for each of these four organisms is listed below.

| Species | Amino Acid 104 |
|---|---|
| Horse | Arginine |
| Gorilla | Leucine |
| Human | Arginine |
| Chimpanzee | Arginine |

The validity of the cladogram is best supported by molecular evidence for which of the following changes in the amino acid composition of the beta-hemoglobin protein during the evolution of these species?

(A) Arginine to leucine at position *X* on the cladogram
(B) Arginine to leucine at position *Y* on the cladogram
(C) Leucine to arginine at position *W* on the cladogram
(D) Leucine to arginine at position *Z* on the cladogram



GO ON TO THE NEXT PAGE.

**Questions 24-27**

Diapause is the interruption of an organism's life cycle in response to environmental cues. The soil nematode *Caenorhabditis elegans* is capable of entering adult reproductive diapause (ARD) when food is scarce. In *C. elegans*, individuals normally become reproductively mature 2 days after hatching and remain fertile for 18 days. They reproduce either by self-fertilization or by mating with another individual.

In an investigation, researchers examined the survival and reproductive success of *C. elegans* following different times in ARD. In the first experiment, groups of *C. elegans* were held in ARD without food for 0–30 days. Upon reintroduction of food, average brood sizes (average number of offspring per adult) were determined following either self-fertilization or mating with a well-fed male. The results are shown in Figure 1.

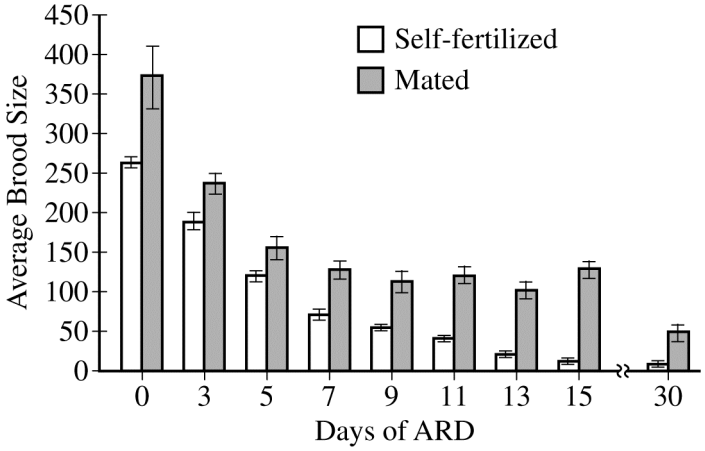



Figure 1. Mean brood sizes $\pm 2SE_{\bar{X}}$ after different times in ARD. Individual *C. elegans* were held in ARD and subsequently allowed to reproduce either via self-fertilization (unshaded bars) or by mating with well-fed males (shaded bars).

In a second experiment, individuals were held in ARD without food for 0–30 days and monitored for average survival times following reintroduction of food (Figure 2).

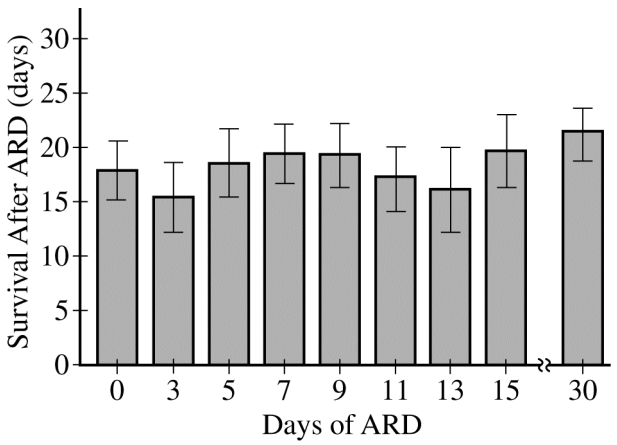



Figure 2. Mean survival $\pm 2SE_{\bar{X}}$ following different times in ARD. Individual *C. elegans* were held in ARD and subsequently given access to food, whereupon their survival times were determined.



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24. Which of the following best describes the reproductive ability of *C. elegans* following the ARD induced in the first experiment?

(A) Mating with a well-fed male consistently produced more offspring than did reproduction via self-fertilization.
(B) The numbers of progeny produced by self-fertilization and by mating with well-fed males were not statistically different.
(C) *C. elegans* stopped reproducing after 20 days without food.
(D) There was no relationship between days without food and average brood size.

25. The average brood size per mated individual upon reintroduction of food following 30 days of ARD is closest to which of the following?

(A) 10
(B) 50
(C) 250
(D) 400

26. Which of the following conclusions is most consistent with the data shown in Figure 2 ?

(A) Animals that spend 3–5 days in ARD are more likely to survive periods of food scarcity than are animals that spend 13–15 days in ARD.
(B) Animals that spend 30 days in ARD live significantly longer after reintroduction of food than animals that spend only 3 days in ARD.
(C) The number of days an animal spends in ARD does not significantly affect its time of survival after reintroduction of food.
(D) The large standard errors of the means make conclusions from the data impossible.

27. Based on the experimental results, which of the following is the best evolutionary explanation for the occurrence of ARD in *C. elegans* ?

(A) The ability to enter ARD provides a strong selective advantage because reproduction can occur despite periods of food scarcity.
(B) Acquiring the genes for ARD gives individuals a selective advantage because they produce more offspring than do individuals who cannot enter ARD.
(C) Individuals who can enter ARD are selected for in the population because they live longer than do individuals who cannot enter ARD.
(D) Individuals who can enter ARD have high fitness because they can reproduce even when food is scarce.



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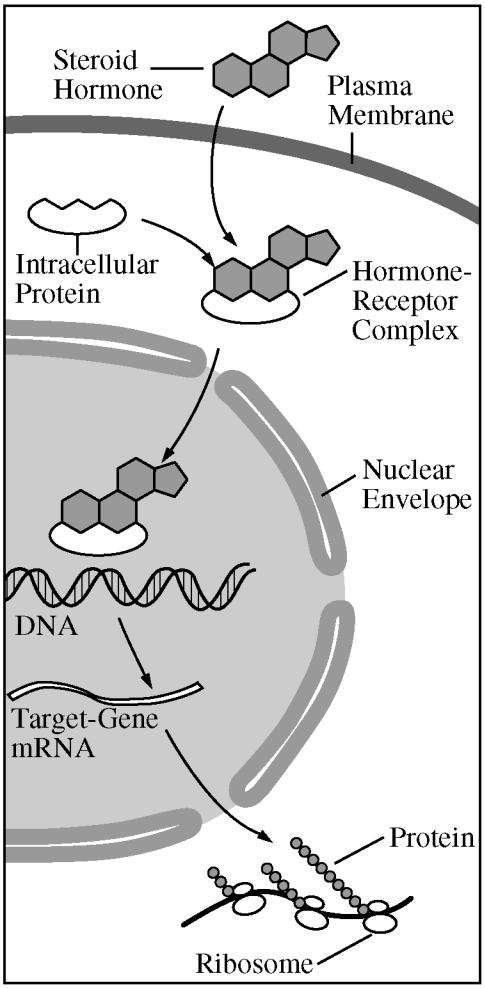
28. Steroid hormones, such as testosterone, pass through the plasma membrane and bind to an intracellular protein, as shown in the diagram below. The hormone-receptor complex then enters the nucleus, where it interacts with DNA to promote transcription of a specific gene.

SIGNALING DIAGRAM FOR STEROID HORMONES




Based on the information presented, which of the following will also occur in response to steroid signaling?

(A) Histone protein synthesis will increase because histones maintain the DNA in an optimal conformation for chromosome assembly.
(B) Ribosome production will increase because ribosomes are specific for the mRNA with which they bind during translation.
(C) DNA replication will increase as a result of the binding of the hormone-receptor complex to the DNA.
(D) Production of a specific mRNA will increase as a result of the binding of the hormone-receptor complex to the DNA.



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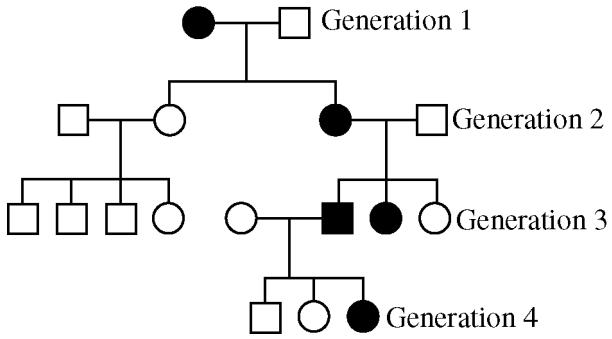
29. The pedigree below shows the inheritance of a dominant allele of a gene in a family over several generations. Circles represent females and squares represent males. Shaded symbols indicate individuals carrying the allele.




The pedigree suggests that the gene is on a nuclear chromosome, and not on mitochondrial DNA, because

(A) mitochondrial genes are not heritable
(B) mitochondrial mutations cannot produce dominant traits
(C) maternal mitochondrial mutations are inherited by all of a mother's offspring
(D) mitochondrial DNA is circular, whereas chromosomal DNA is linear



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30. High blood cholesterol (hypercholesterolemia, HC) can lead to cardiovascular problems such as atherosclerosis and heart attack. Exercise and monitoring of diet can often control cholesterol levels; however, in certain cases HC is inherited as an autosomal dominant disease caused by a mutation in a single gene.

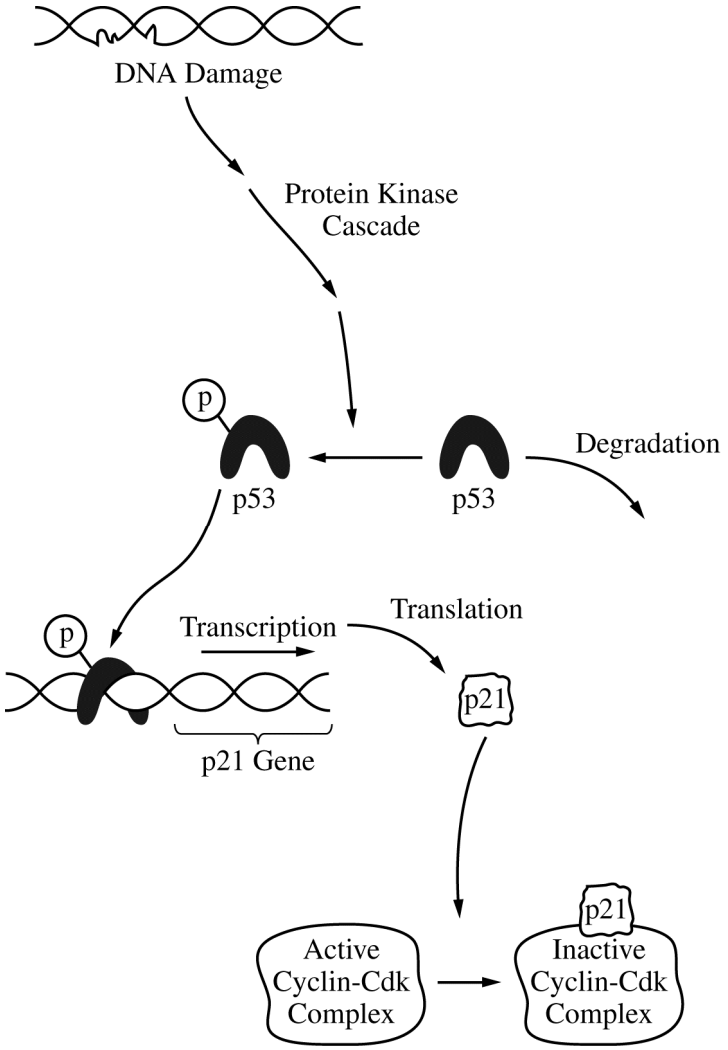
    A man with high cholesterol levels is about to marry a woman whose total cholesterol levels are also higher than average. A physician has suggested they get tested for the *HC* allele. Which of the following is a valid ethical question concerning the test?

    (A) How important are the results of the test to the couple's health, since they already know they have HC?
    (B) How can they eliminate the allele for HC from their cells?
    (C) If both have the allele for HC, should an insurance company raise their rates because of the results of the test?
    (D) What cures are available for HC other than dietary changes and exercise?

31. A cell is treated with a drug that prevents the formation of new lysosomes. The cell continues to transcribe the genes that code for the hydrolytic enzymes that are normally found in lysosomes and continues to translate the mRNAs for those proteins on membrane-bound ribosomes.

    The hydrolytic enzymes are most likely to accumulate in which of the following cellular structures?

    (A) Nucleus
    (B) Mitochondrion
    (C) Smooth endoplasmic reticulum
    (D) Golgi complex




32. The p53 protein regulates a cellular response to DNA damage. Based on the diagram above, which of the following best describes the role of p53 in the response to DNA damage?

(A) Phosphorylated p53 binds to DNA and repairs the damage.
(B) Phosphorylated p53 stimulates transcription of p21, and the resulting p21 protein suppresses cell division until the DNA damage is repaired.
(C) Phosphorylated p53 binds cyclin-Cdk complexes, and the resulting protein complex repairs the DNA damage.
(D) Phosphorylated p53 activates p21 proteins, and the p21 proteins in turn repair the DNA damage.



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**Questions 33-37**

Students investigated the effect of light on the carbon cycle in aquatic ecosystems by performing the controlled experiment summarized below. The students placed equal amounts of water (pH 7.0) from a large aquarium in glass beakers. The students transferred aquatic plants from the aquarium to several of the beakers, and then they placed equal numbers of the beakers in the light or the dark (Figure 1: groups I and II). Similarly, the students transferred goldfish from the same aquarium to other beakers, and then they placed equal numbers of those beakers in the light or dark (Figure 1: groups III and IV). Finally, the students placed an equal number of beakers containing water only in the light or dark (Figure 1: groups V and VI).

After exposing the samples to light or dark for one hour, the students recorded the pH of the water in each beaker. Carbon dioxide dissolved in water will lower the pH of an aqueous solution. In the experiment, the students used changes in pH to monitor changes in the amount of carbon dioxide in the water. For each treatment group, the students calculated the mean pH and standard error, as documented in the table below.

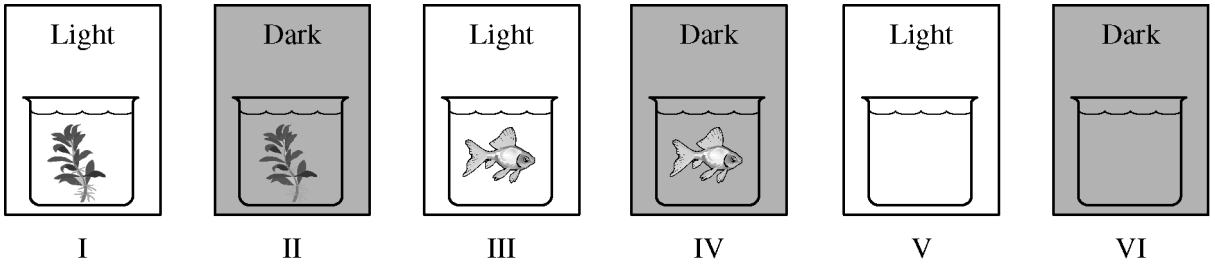


Figure 1. Treatment groups

MEAN pH OF TREATMENT GROUPS AFTER 1 HOUR

| Treatment group ($n$ = 10) | I | II | III | IV | V | VI |
|---|---|---|---|---|---|---|
| Mean pH | 8.2 | 6.4 | 5.9 | 5.6 | 7.3 | 6.8 |
| Standard error of the mean | 0.3 | 0.3 | 0.2 | 0.3 | 0.5 | 0.4 |



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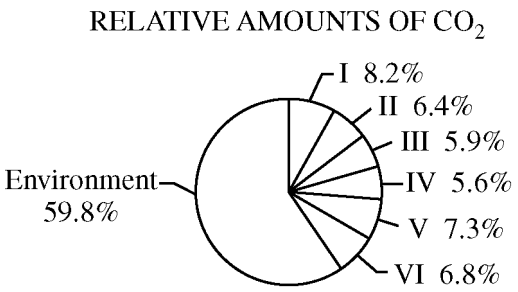
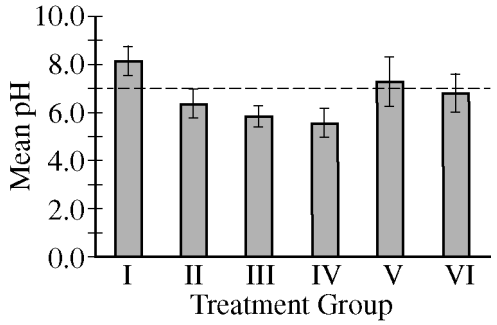
33. Which of the following graphs is the most appropriate representation of the experimental results documented in the table?

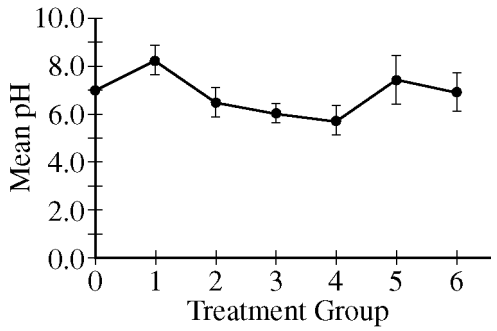
(A)



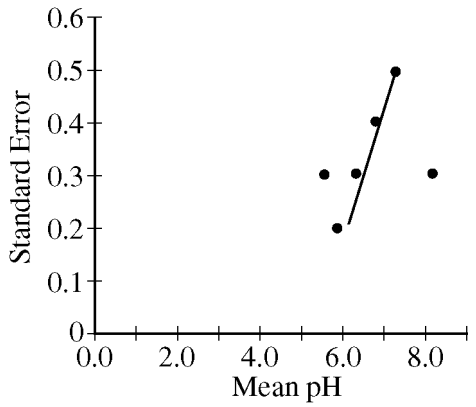

(B)




(C)




(D)




34. Which of the following observations provides the best evidence that photosynthesis occurred in treatment group I?

(A) The specimens in the beakers were aquatic plants from a large aquarium.
(B) The beakers were placed in the light.
(C) The mean pH of the samples increased after one hour.
(D) The standard error of the mean was smaller than that for treatment group V.

35. To investigate whether an organism in the study is capable of both photosynthesis and respiration, a comparison of which treatment groups is most appropriate?

(A) I and II
(B) II and IV
(C) III and V
(D) IV and VI

36. The results for treatment groups V and VI could suggest which of the following questions about the design of the experiment?

(A) Do the glass beakers prevent light from reaching the test samples?
(B) Is the method used for measuring pH harmful to aquatic organisms?
(C) Is the availability of carbon dioxide a limiting factor in aquatic ecosystems?
(D) Does the aquarium water contain living microorganisms?

37. Which of the following modifications to the experimental design will best help reduce the standard errors of the means?

(A) Using pond water instead of aquarium water
(B) Exposing samples to light for a greater amount of time
(C) Increasing the sample size of each treatment group
(D) Collecting organisms from a natural water source instead of an aquarium



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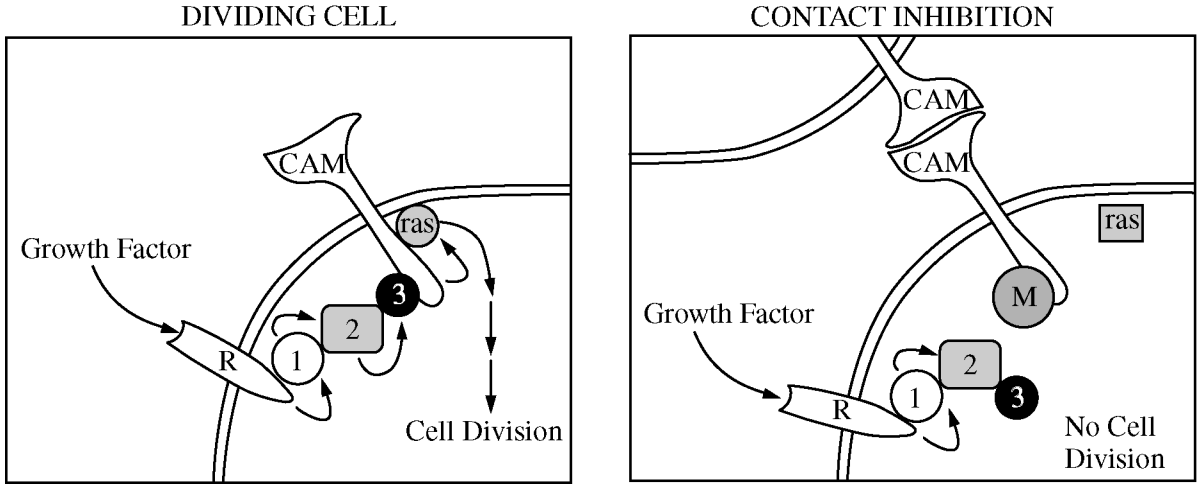
38. Many human cells can be stimulated to divide by hormonelike growth factors that bind to receptor proteins (R) on the plasma membrane and trigger an internal signal-transduction cascade. In many cases, however, the process of contact inhibition prevents mitosis when cells are in direct contact with one another. Contact inhibition occurs when proteins called cell adhesion molecules (CAMs) interact, causing them to change shape so that the growth-factor signaling proteins that normally associate with CAMs are replaced by another protein, called M. Both pathways are depicted in the figures below.




Which of the following statements accurately uses the information presented to support the hypothesis that interruption of M function in a single body cell can result in cancer?

(A) Protein 3 will be prevented from interacting with CAMs, causing the cell cycle to stop permanently.
(B) The ras protein will remain bound to DNA, blocking expression of genes required for mitosis.
(C) Growth-factor signaling can trigger mitosis in cells that are in direct contact with other cells.
(D) The receptor proteins of body cells will no longer bind to growth-factor proteins.



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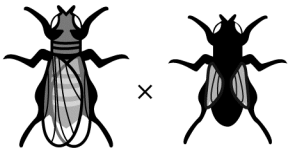
FRUIT FLY EXPERIMENTAL RESULTS



*BbVv*
Wild-Type Female
(tan body, wild-type wings)

×

*bbvv*
Mutant Male
(black body, vestigial wings)

| Genotypes | *BbVv* Tan, Wild Type | *bbvv* Black, Vestigial | *Bbvv* Tan, Vestigial | *bbVv* Black, Wild Type |
|---|---|---|---|---|
| Expected results | 862 | 862 | 862 | 862 |
| Observed phenotypes | 1,447 | 1,416 | 309 | 277 |

39. In *Drosophila melanogaster* the allele for wild-type tan body color (*B*) is dominant to the recessive allele for black body color (*b*). Similarly, the allele for wild-type wing shape (*V*) is dominant to the recessive allele for vestigial wing phenotype (*v*). In the cross diagrammed above, the expected and observed results are shown. Which of the following best explains the observed results of the cross?

(A) The alleles for body color and wing shape assort independently, as predicted by Mendel's laws.
(B) The genes for body color and wing shape are located close to each other on the same chromosome.
(C) The traits of body color show complete dominance over the traits of wing shape.
(D) The observed variations in body color and wing shape are detectable in males but not in females.

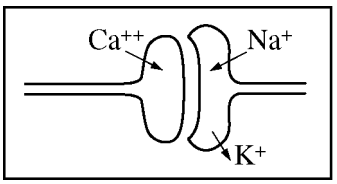
40. Some cells release active signaling proteins when membrane-bound precursor proteins are cleaved by proteolytic enzymes. The signaling proteins can then bind to receptors on the surface of a target cell, thereby activating an intracellular signaling pathway and eliciting a response from the target cell.

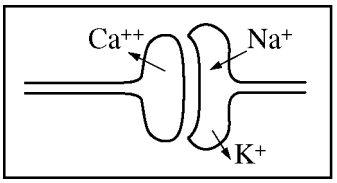
    This mechanism of activating receptor-binding signaling proteins has been observed in a variety of organisms from bacteria to humans. Many of the enzymes responsible for proteolysis of membrane-bound precursor proteins have been isolated and characterized.

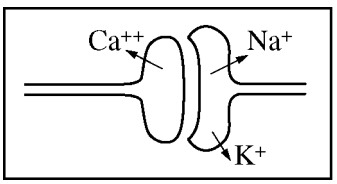
    Which of the following questions would be most appropriate to investigate whether the proteolytic enzymes are evolutionarily conserved among species?

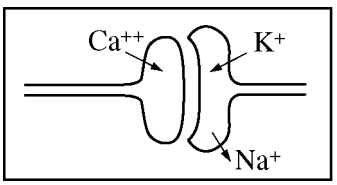
    (A) Are the genes encoding the proteolytic enzymes expressed in the same cell types in all species?
    (B) Once the precursor proteins of different species are cleaved, do the active signaling proteins bind to the same receptors on different target cells?
    (C) If a proteolytic enzyme from one species is incubated with a precursor protein from another species, does correct cleavage occur?
    (D) Are the proteolytic enzymes synthesized in the rough endoplasmic reticulum of all species?

41. Transmission of an action potential across a synapse involves the release of neurotransmitters by the presynaptic neuron. The arrival of the action potential triggers a rise in the calcium concentration in the synaptic terminal, and the change in concentration triggers a release of neurotransmitters into the synaptic cleft. Which of the following representations of the movement of calcium, sodium, and potassium ions best shows how an action potential is transmitted to the postsynaptic neuron?

(A)



(B)



(C)



(D)


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42. The table below provides a comparison of nitrogenous waste production in selected organisms.

| Nitrogenous Waste | Solubility in Water | Amount of Water Required for Excretion | Organisms that Primarily Produce the Nitrogenous Waste |
|---|---|---|---|
| Ammonia | High | High | Freshwater fish, aquatic invertebrates |
| Urea | Medium | Medium | Mammals, sharks |
| Uric acid | Very low | Very low | Birds, reptiles, and most terrestrial insects and arthropods |

Which of the following statements is most consistent with the data in the table?

(A) In response to the hypotonic environment in which freshwater fish live, they excrete ammonia in concentrated urine or across their gills.
(B) The kidneys of reptiles and birds are highly efficient because little water is needed to excrete uric acid.
(C) Birds excrete ammonia in addition to uric acid, and the ratio of the two substances is independent of whether the birds are primarily terrestrial or aquatic species.
(D) The similar regulation of extracellular fluid volume and composition in all the organisms suggests conservation of kidney structure throughout evolution.



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**Questions 43-48**

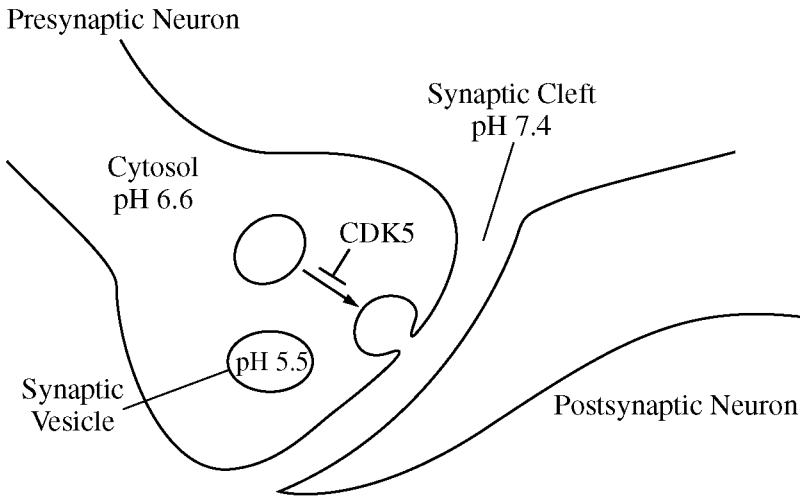


Figure 1. Model of synapse

Researchers investigating the regulation of neurotransmitter release from presynaptic neurons proposed a model (Figure 1) in which CDK5, a protein expressed in axon terminals, inhibits the movement of synaptic vesicles to the presynaptic membrane.

To test their model, the researchers used a modified version of green fluorescent protein (GFP*). In slightly alkaline conditions, GFP* exhibits a bright green fluorescence. In acidic conditions, GFP* exhibits no fluorescence. Using standard techniques, the gene encoding GFP* is easily introduced into living cells. By engineering the expression of GFP* in laboratory-cultured nerve cells, the researchers found that a bright green fluorescence was exhibited only when a presynaptic neuron was given a certain stimulus.

43. Based on the model, which of the following best explains why a bright green fluorescence was observed following stimulation of a presynaptic neuron?

(A) GFP* synthesis was activated when a gene taken up by the neuron was switched on.
(B) GFP* stored in the cytoplasm of the neuron was packaged into synaptic vesicles.
(C) GFP* contained in synaptic vesicles moved into the synaptic cleft by exocytosis.
(D) GFP* present in the synaptic cleft was reabsorbed by endocytosis into the neuron.

44. Which of the following best explains why GFP* might exhibit a bright green fluorescence in alkaline conditions but not in acidic conditions?

(A) Addition of an $H^+$ to GFP* at acidic pH changes the shape of the protein, preventing fluorescence.
(B) CDK5 is a degrading enzyme that hydrolyzes GFP* at alkaline pH, preventing fluorescence.
(C) An influx of protons into the axon terminal activates synthesis of new GFP* molecules, preventing fluorescence.
(D) Packaging of GFP* into synaptic vesicles is triggered by a sudden drop in cytosolic pH, preventing fluorescence.

45. Which of the following observations best supports the hypothesis that CDK5 negatively regulates neurotransmitter release?

(A) Introduction of CDK5 protein into neurons results in the movement of synaptic vesicles to the plasma membrane in the absence of any stimulus.
(B) Uptake of a gene encoding CDK5 by neurons results in the movement of synaptic vesicles to the plasma membrane in the absence of any stimulus.
(C) Suppression of CDK5 expression in neurons inhibits the movement of synaptic vesicles to the plasma membrane in response to a specific stimulus.
(D) Inhibition of CDK5 activity in neurons increases the movement of synaptic vesicles to the plasma membrane in response to a specific stimulus.

46. Based on the model, which of the following describes the most likely mechanism by which CDK5 regulates neurotransmitter release?

(A) CDK5 adds methyl groups to DNA, altering expression of genes required for synthesis of neurotransmitters.
(B) CDK5 promotes the rearrangement of the lipid molecules of two bilayers into a single membrane.
(C) CDK5 alters the activity of other proteins involved in the movement of synaptic vesicles to the plasma membrane.
(D) CDK5 binds to gated ion channels in the postsynaptic membrane, resulting in diffusion of calcium ions.

47. Previous experiments indicate that CDK5 is active only when attached to a protein called p35. Which of the following best predicts how p35 might play a role in regulating neuron function?

(A) Elevated intracellular levels of p35 result in increased synaptic activity.
(B) Degradation of p35 results in increased synaptic activity.
(C) Reabsorption of p35 from the synaptic cleft results in increased synaptic activity.
(D) Attachment of p35 to synaptic vesicles results in increased synaptic activity.

48. Based on the model, which of the following best explains how regulation of neurotransmitter release might increase the range of responses to a stimulus in the nervous system?

(A) In the absence of any stimulus, neurons can still release neurotransmitters.
(B) Different neurons in the same neural network can release different amounts of neurotransmitter.
(C) In the depolarization phase of an action potential, postsynaptic neurons can adjust the amount of neurotransmitter bound to receptors on their surface.
(D) In the recovery phase following a stimulus, enzymes can be mobilized to degrade molecules present in the synaptic vesicles.



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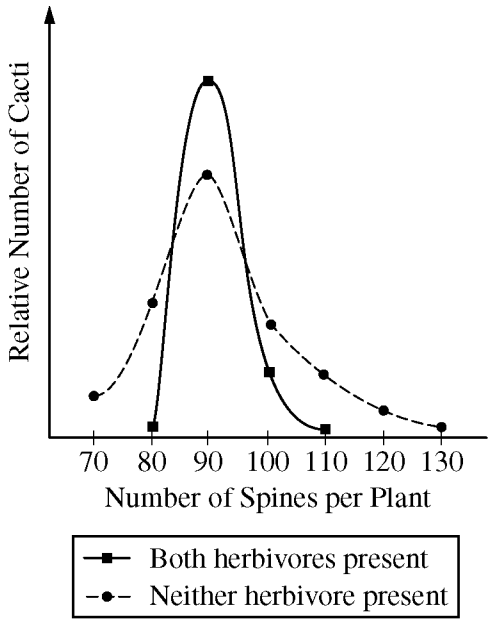



49. In a species of cactus, the number of spines on a plant is genetically determined. The graph above shows frequency distributions for populations of the cactus species growing in the presence or absence of two herbivores: peccaries (a New World pig) and wasp larvae. Which of the following best accounts for the different frequency distributions in the graph?

(A) Peccaries eat cacti with the greatest number of spines, and wasp larvae show no preference with respect to spine number.
(B) Peccaries eat cacti with a smaller number of spines, and wasp larvae eat cacti with a greater number of spines.
(C) Wasps have increasing difficulty depositing eggs on cacti with more spines, and peccaries show no preference with respect to spine number.
(D) Both peccaries and wasp larvae will eat the most abundant types of cacti, which are the plants with the greatest number of spines.



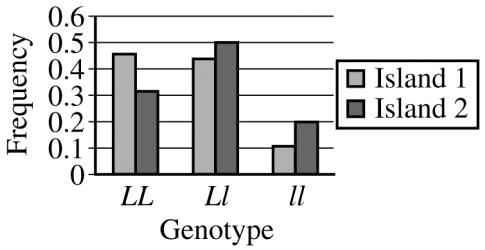
GO ON TO THE NEXT PAGE.

50. Scientists are studying several populations of finches on neighboring islands in the South Pacific. Previous genetic analysis has shown that a single gene controls tail-feather length in the finch populations and that the allele for long tail feathers (*L*) is dominant to the allele for short tail feathers (*l*). On two separate islands, the scientists recorded the number of finches with long tail feathers and the number of finches with short tail feathers. The results are shown in the table below.

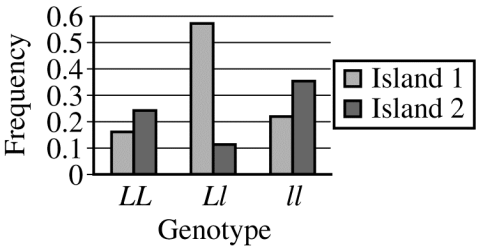
| Location | Phenotype | Number of Individuals |
|---|---|---|
| Island 1 | Long tail feathers | 1,582 |
| | Short tail feathers | 598 |
| | Total count | 2,180 |
| Island 2 | Long tail feathers | 2,432 |
| | Short tail feathers | 1,110 |
| | Total count | 3,542 |

If the two finch populations are each in Hardy-Weinberg equilibrium and are isolated from each other, then which of the following graphs correctly displays the relative genotype frequencies?

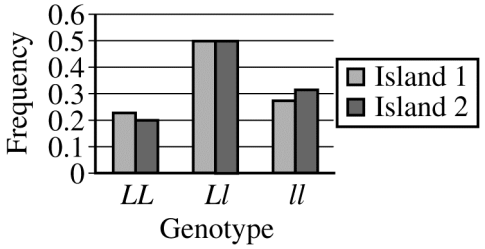
(A)



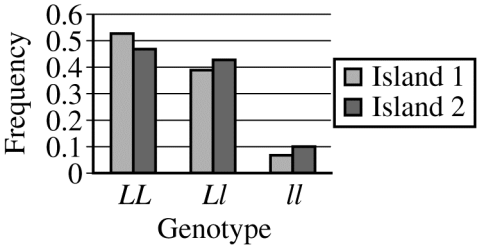

(B)




(C)




(D)



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Second Base in Codon

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

5′-GACCGCAUGGUGACGAAAUUUGGCCAUUAA-3′

51. Based on the universal genetic code, which of the following represents the correct polypeptide that will result from translation of the mRNA molecule shown, beginning with the first available start codon?

(A) Asp-Arg-Met-Val-Thr-Lys-Phe-Gly-His
(B) Met-Arg-Asp-Stop-His-Gly-Phe-Lys-Thr-Val
(C) Met-Val-Thr-Lys-Phe-Gly-His
(D) Val-Thr-Lys-Phe-Gly-His



GO ON TO THE NEXT PAGE.

| | Cross 1 | | Cross 2 | | Cross 3 | |
|---|---|---|---|---|---|---|
| Parents | Blue Male × Blue Female | | Blue Male × White Female | | White Male × Blue Female | |
| Offspring | Males | Females | Males | Females | Males | Females |
| | 60 blue | 124 blue | 0 blue | 115 blue | 48 blue | 42 blue |
| | 52 white | 0 white | 108 white | 0 white | 53 white | 49 white |

52. The data above represent the results of three different crosses involving the inheritance of a gene that determines whether a certain organism is blue or white. Which of the following best explains the mechanism of inheritance of the gene?

(A) The allele for white is an autosomal dominant allele because a 1:1 phenotype ratio of blue to white among both sexes is observed in cross 3.
(B) The allele for blue is an autosomal dominant allele because an approximate 3:1 phenotype ratio of blue to white is observed in cross 1.
(C) The allele for white is an X-linked dominant allele because no white females are produced in cross 1.
(D) The allele for blue is an X-linked dominant allele because there are no blue male offspring in cross 2.

---

| | Population 1 | | Population 2 | |
|---|---|---|---|---|
| **Year** | **Allele *R*** | **Allele *r*** | **Allele *R*** | **Allele *r*** |
| 1980 | 0.3 | 0.7 | 0.37 | 0.63 |
| 2010 | 0.0 | 1.0 | 0.75 | 0.25 |

53. The table shows the changes in allele frequencies of a specific gene in two populations of randomly mating small mammals after 30 years. The populations inhabit adjacent equatorial islands that have similar topography and climate. Which of the following is the most reliable conclusion that can be drawn from analysis of the data above?

(A) Genetic drift has occurred in population 1.
(B) Population 2 is in Hardy-Weinberg equilibrium.
(C) Selection for allele *r* is occurring in both populations.
(D) The reduced frequency of allele *R* in population 1 will eventually lead to the extinction of population 1.



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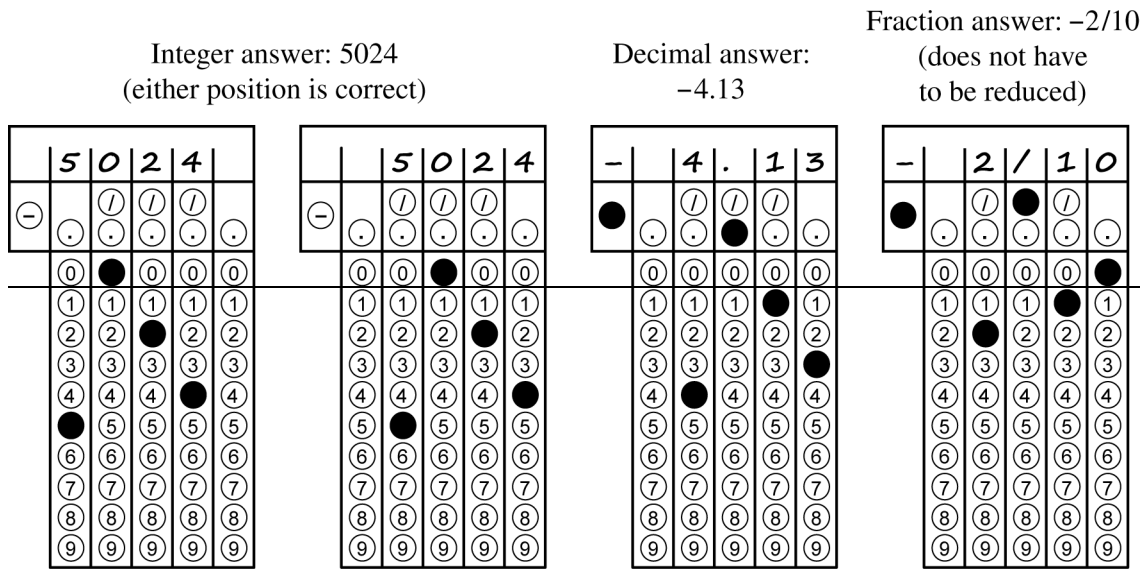
**Directions:** The next five questions, numbered 121–125, require numeric answers.
Determine the correct answer for each question and enter it in the grid on page 3 of the answer sheet.
Use the following guidelines for entering your answers.

- 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).

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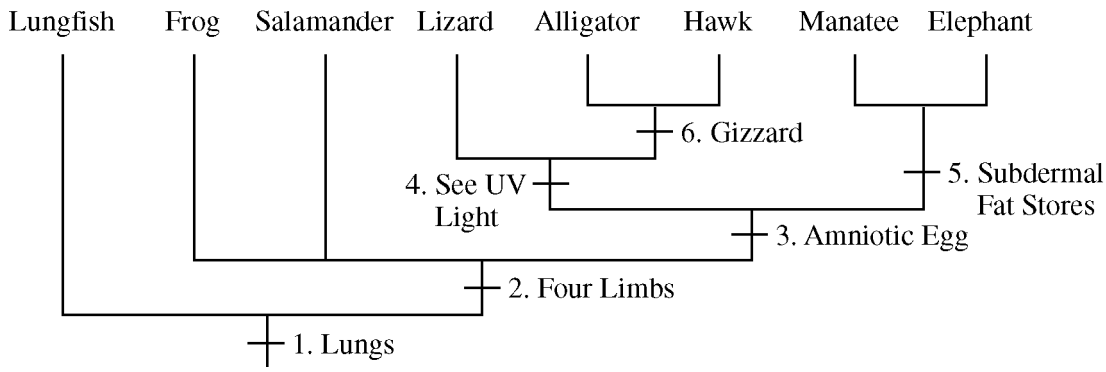



121. The cladogram above shows proposed phylogenetic relationships for several vertebrates. Selected derived characters are indicated on the cladogram by numbered labels. Based on the information presented, which of the derived characters is shared by alligators and manatees but not salamanders? Give your answer as the number label of a character indicated on the cladogram.



GO ON TO THE NEXT PAGE.

122. In fruit flies, the allele for vestigial wings is recessive to the allele for wild-type wings, and the allele for white eyes is recessive to the allele for red eyes. The gene controlling wing type is carried on an autosome, whereas the gene controlling eye color is carried on the X chromosome.

A true-breeding female with wild-type wings and white eyes is crossed with a male with vestigial wings and red eyes. What proportion of the offspring are expected to be males with wild-type wings and white eyes? Give your answer as a fraction or a decimal value from 0 to 1.

123. ABO blood type in humans is determined by three alleles of a single gene: $I^A$, $I^B$, and $i$. The $I^A$ and $I^B$ alleles are codominant, and both alleles are completely dominant to the $i$ allele.

Shown in the table are the approximate genotype frequencies of ABO blood types for a large human population.

| Phenotype | Genotype | Frequency |
|---|---|---|
| Type A | $I^AI^A$ or $I^Ai$ | 0.41 |
| Type B | $I^BI^B$ or $I^Bi$ | 0.10 |
| Type AB | $I^AI^B$ | 0.04 |
| Type O | $i\,i$ | 0.45 |

The Hardy-Weinberg principle can be applied to a genetic locus with three alleles by using the following equations.

$$p^2 + q^2 + r^2 + 2pq + 2pr + 2qr = 1$$
$$p + q + r = 1$$

Assuming that the population is in Hardy-Weinberg equilibrium with respect to blood type, what is the frequency of the $i$ allele? Give your answer to two decimal places.



GO ON TO THE NEXT PAGE.

124. Biological communities containing a large number of species that are evenly distributed exhibit high species diversity—a concept that encompasses both species richness (the number of different species present) and relative abundance (the number of individuals of each species). One measure of species diversity is Simpson's index of diversity, which is represented by the following mathematical equation.

$$D_s = 1 - \frac{\sum n_i(n_i - 1)}{N(N - 1)}$$

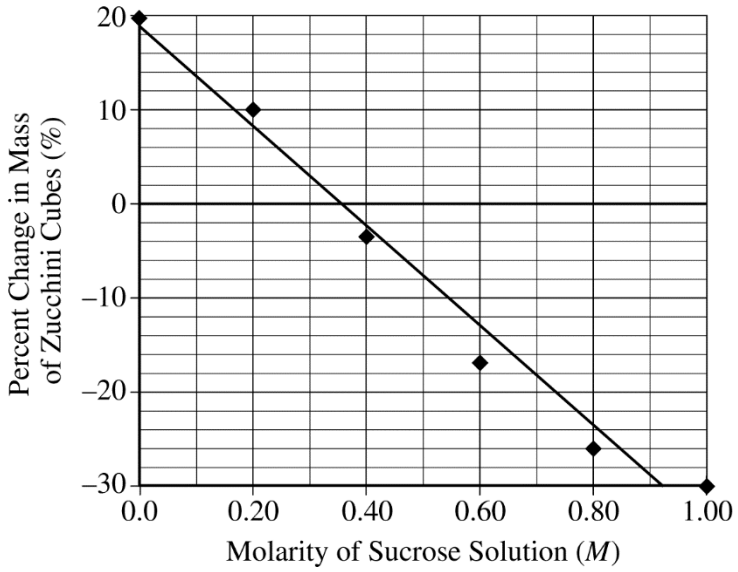
Where $D_s$ = index of diversity for a community
$N$ = total number of individuals of all species
$n_i$ = number of individuals in each individual species

The following data were collected from a community of trees.

| Species | Number of Individuals |
|---|---|
| 1 | 20 |
| 2 | 34 |
| 3 | 4 |
| 4 | 10 |
| Total | 68 |

Calculate the Simpson's index of diversity for the community of trees. Enter your answer as a value between 0 and 1 to the nearest hundredth.

125. A zucchini squash was peeled and cut into six identical cubes. After being weighed, each cube was soaked in a different sucrose solution for 24 hours in an open container and at a constant temperature of 21ºC. The cubes were then removed from the sucrose solutions, carefully blotted on paper towels, and weighed again. The percent change in mass (due to a net gain or loss of water) was calculated for each cube, and the results are shown in the graph below. A straight line is drawn on the graph to help in estimating results from other sucrose concentrations not tested.




Using the straight line on the graph above, calculate the water potential (in bars) of the zucchini squash at 21°C. Give your answer to one decimal place.

**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.**

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**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 2016 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

2016

**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. You may begin writing your responses before the reading period is over.

**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. You may begin writing your responses before the reading period is over.

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

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

**Form I**
**Form Code 4MBP4-S**

# AP® BIOLOGY EQUATIONS AND FORMULAS

## Statistical Analysis and Probability

**Mean**

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

**Standard Deviation**

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

**Standard Error of the Mean**

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

**Chi-Square**

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

**Chi-Square Table**

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

**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

$\bar{x}$ = 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.

**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 | $\mu$ |
| $10^{-9}$ | 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 ($\Psi$)**

$$\Psi = \Psi_P + \Psi_S$$

$\Psi_P$ = pressure potential

$\Psi_S$ = 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**

$A = \Sigma$ surface area of each side

$r$ = radius

$\ell$ = length

$h$ = height

$w$ = width

$s$ = length of one side of a cube

$A$ = surface area

$V$ = volume

$\Sigma$ = 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**

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

$\Delta G$ = change in Gibbs free energy

$\Delta S$ = change in entropy

$\Delta H$ = change in enthalpy

$T$ = absolute temperature (in Kelvin)

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

## BIOLOGY

**Section II**

**8 Questions**

**Total Time—90 minutes**

**Reading Period—10 minutes**

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

**Question 1 is on the following page.**

**GO ON TO THE NEXT PAGE.**

1. In an investigation of the effect of a particular insecticide on plant growth and development, researchers established 20 test plots containing mature *Haplopappus squarrosus* shrubs. *H. squarrosus* is pollinated by certain species of insects and is eaten by other species of insects. Ten test plots were sprayed with the water-soluble insecticide, and ten test plots were sprayed with water only. The researchers recorded the numbers of plants or plant parts at different life stages in each test plot. The results of the investigation are shown in the table.

EFFECT OF INSECTICIDE TREATMENT ON PLANT GROWTH AND DEVELOPMENT

| | | Treatment | | |
|---|---|---|---|---|
| | | Water Spray | Insecticide Spray | |
| Plant Life Stage | Plant or Plant Part | Mean Density $\pm 2SE_{\bar{X}}$ (numbers/m$^2$) | | P-values* |
| Flowering | Flowers | 8,220 ± 360 | 9,490 ± 1900 | ≥0.05 |
| Seed formation | Immature seeds | 2,440 ± 78 | 3,100 ± 480 | ≥0.05 |
| Seed maturation | Mature seeds | 60 ± 44 | 1,200 ± 1020 | ≤0.001 |
| Seedling development | Seedlings | 1.4 ± 0.4 | 33.1 ± 15 | ≤0.01 |
| *based on an analysis of variance (ANOVA) test | | | | |

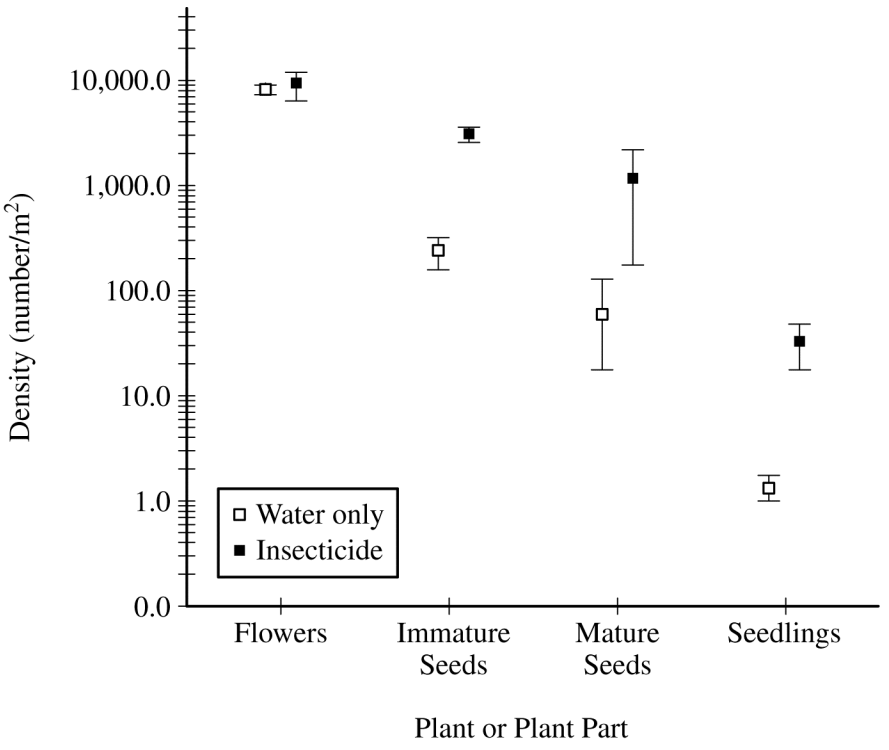


Figure 1. Student-constructed graph of data with a plotting error



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(a) **Identify** the control treatment in the original experiment. **Provide reasoning** to support the researcher's decision to not use a set of unsprayed plants as a control.

(b) A student incorrectly plotted one value from the table on a graph (Figure 1). **Identify** the error in the student-constructed graph. **Provide reasoning** to support the student's choice of a logarithmic scale on the Y axis.

(c) Using the template provided, **calculate** the percent of plants or plant parts remaining from one life stage to the next life stage. Round your answer to one decimal place. Based on your calculations, **identify** the plant life stage at which the insects have the greatest impact on the life cycle of the plant. **Justify** your answer. **Describe** the most likely interaction between the insects and the plants.

(d) In a second experiment, researchers used a different insecticide that affects a different group of insects. In this treatment, the number of seeds formed was greatly reduced compared to the control. Based on this observation, **describe** the most likely interaction between the affected insects and the plants in this experiment. **Justify** your response.

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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.**



GO ON TO THE NEXT PAGE.

PAGE FOR ANSWERING QUESTION 1

| Plant Life Stage | Water Spray | Percent Remaining | Insecticide Spray | Percent Remaining |
|---|---|---|---|---|
| Flowering | 8220 | | 9490 | |
| Seed Formation | 2440 | | 3100 | |
| Seed Maturation | 60 | | 1200 | |
| Seedling Development | 1.4 | | 33.1 | |

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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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Figure 1. Diagram of the choice chamber used to measure host preference of mosquitoes

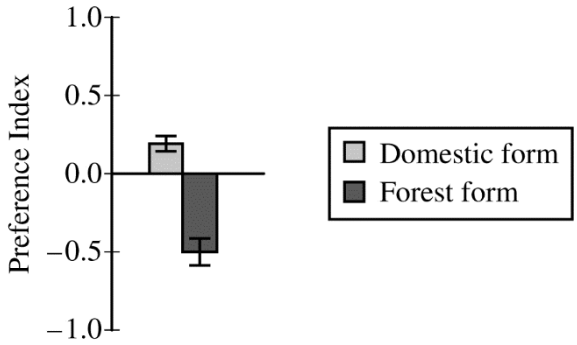


Figure 2. Mean host preference index $\pm 1 SE_{\bar{X}}$ of forest and domestic forms of mosquitoes. A positive value indicates preference for a human host, and a negative value indicates preference for a guinea pig host.

2. The yellow-fever mosquito (*Aedes aegypti*) is a major vector of human disease. In a particular location in Africa, there are two forms of the mosquito. The forest form of the mosquito is black and often lays its eggs in tree holes and pools of water in the forest. The domestic form of the mosquito is brown and prefers to lay its eggs in rainwater collected near human dwellings.

   Researchers used a choice chamber (Figure 1) to investigate the host preference of *A. aegypti*. The researchers recorded the number of forest-form and domestic-form mosquitoes that bit human or guinea pig hosts during several ten-minute trials. The researchers used these data to calculate a host-preference index for each form, as shown in Figure 2. Researchers also identified a gene in the mosquitoes, *OR4*, that encodes an olfactory receptor. A volatile odorant, sulcatone, binds to the OR4 receptor. Humans produce higher levels of sulcatone than do guinea pigs.

   (a) Based on an analysis of the data, **identify** the preferred host of the forest form and of the domestic form of the mosquito.

   (b) **Propose a refinement** to the initial experimental design that will rule out the possibility that preference is based on a visual cue. **Propose** a different refinement to the initial experiment to test whether sulcatone is the attractant for the human-preferring form.

   (c) **Predict** how each of the following mutations in the *OR4* gene would most likely affect the sensitivity of mosquitoes to sulcatone. **Justify** each prediction.

   - A mutation that results in the removal of the intracellular domain of the receptor protein
   - A mutation that results in the substitution of a small hydrophobic amino acid for another small hydrophobic amino acid in the ligand-binding site of the receptor protein

   (d) A researcher proposes that the two forms of mosquito are evolving into two different species. **Identify** ONE potential postzygotic isolating mechanism, and **describe** how the isolating mechanism would result in the evolution of the two forms into different species.

**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.**

**GO ON TO THE NEXT PAGE.**

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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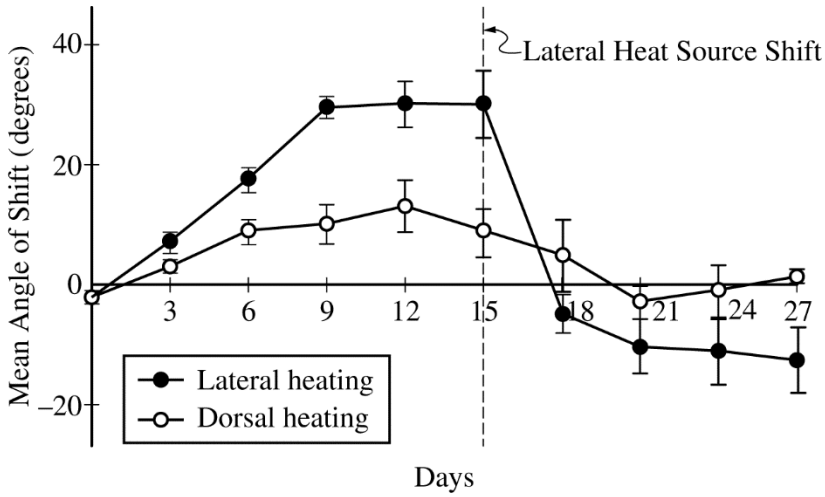


Figure 1. Mean angle of the shift in turtle embryo position following exposure to a directional heat source. The error bars represent $\pm 2SE_{\bar{X}}$.

3. A certain species of turtle (*Pelodiscus sinensis*) lays its eggs in nests that are buried in the sand. The turtle then leaves the eggs to develop. A researcher claims that turtle embryos are able to shift within their eggs in response to directional thermal cues in the environment. To test the claim, the researcher incubated turtle eggs in containers and used heating pads to deliver heat either to the top of the container (dorsal heating) or to one side of the container (lateral heating). The position of the lateral heat source was switched from one side to the other on day 15. The researcher recorded the shifts in embryo position relative to the initial embryo position in the egg. The results are shown in Figure 1.

   (a) **Indicate** whether the researcher's claim that turtle embryos within their eggs respond to thermal cues is supported or not supported. Using the data, **justify** your response.

   (b) The researcher used the dorsal heat treatment as the control. **Propose** a different treatment that would have been another valid control.

   (c) The researcher hypothesizes that when turtle embryos respond to thermal cues they develop more rapidly than do turtle embryos that do not respond to thermal cues. **Describe** ONE potential advantage for turtles having a shorter embryonic period.

PAGE FOR ANSWERING QUESTION 3



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ADDITIONAL PAGE FOR ANSWERING QUESTION 3

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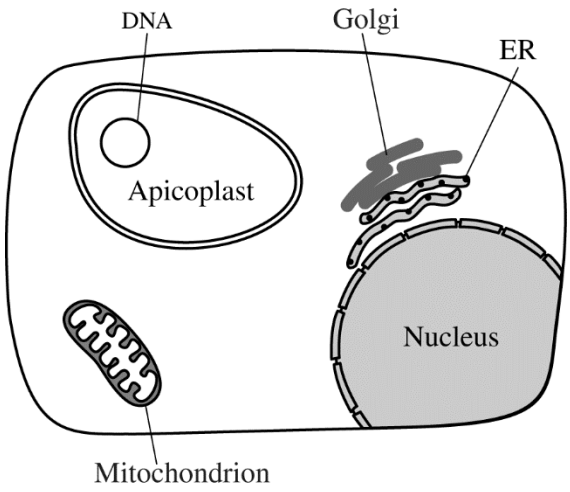


Figure 1. Simplified diagram of the cellular structures of *Plasmodium falciparum*

4. The eukaryotic protozoan parasite *P. falciparum* is the causative agent of malaria. *P. falciparum* cells contain an organelle called the apicoplast (see Figure 1). Apicoplasts synthesize precursors of biomolecules that are required for growth and reproduction of the parasite.

   (a) Based on Figure 1, **describe** TWO pieces of evidence a researcher could use to support the claim that apicoplasts evolved from free-living, prokaryotic organisms.

   (b) Doxycycline is a drug used to treat malaria and some bacterial infections. Doxycycline binds to the prokaryotic 30S ribosomal subunit and inhibits its function. **Explain** how doxycycline can be an effective treatment for a *P. falciparum* infection in humans.

PAGE FOR ANSWERING QUESTION 4

ADDITIONAL PAGE FOR ANSWERING QUESTION 4

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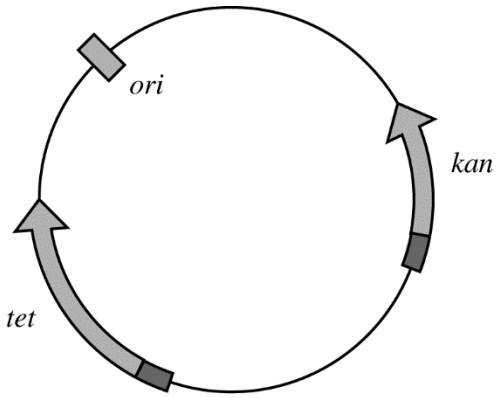


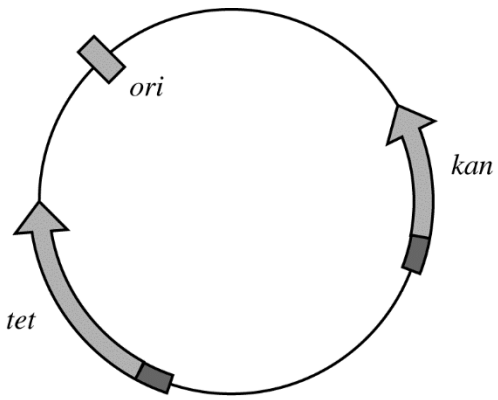

p*TET-KAN*

5. The p*TET-KAN* plasmid carries an origin of replication (*ori*) and genes conferring resistance to the antibiotics tetracycline (tet) and kanamycin (kan) as represented in the figure. Cultures of *E. coli* bacteria were transformed with the plasmid. To determine the success of the transformation experiment, the bacterial cells were cultured in the presence or absence of tetracycline overnight.

   (a) **Predict** the most likely outcome of culturing transformed *E. coli* in the presence of tetracycline. **Justify** your prediction.

   (b) Researchers inserted a small fragment of human DNA into the p*TET-KAN* plasmid. Cultures of *E. coli* were transformed with the modified plasmid. The transformed bacterial cells were able to survive in the presence of tetracycline but were unable to survive in the presence of kanamycin. **Draw** an "X" on the plasmid template provided below to indicate where the human DNA fragment was most likely inserted. **Justify** your placement of the inserted human DNA.

PAGE FOR ANSWERING QUESTION 5




p*TET-KAN*



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ADDITIONAL PAGE FOR ANSWERING QUESTION 5

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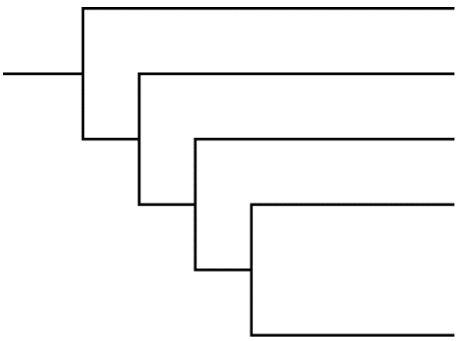
NUMBER OF DIFFERENCES IN THE FIRST 60 AMINO ACIDS OF THE NEUROMODULIN PROTEIN ISOLATED FROM FIVE SPECIES

| | Finch | Gecko | Turtle | Frog | Zebra fish |
|---|---|---|---|---|---|
| Finch | 0 | 2 | 2 | 6 | 10 |
| Gecko | | 0 | 1 | 7 | 11 |
| Turtle | | | 0 | 7 | 11 |
| Frog | | | | 0 | 13 |
| Zebra fish | | | | | 0 |

6. Neuromodulin is an essential protein that is highly conserved among vertebrates. Researchers compared the first 60 amino acids of the neuromodulin protein from each of five different species. The results are shown in the table above.

   Based on the data in the table, **construct** a cladogram on the template provided to represent the evolutionary relatedness of the five species. Using the data, **justify** the placement of the zebra fish on the cladogram. On the cladogram, circle the position of the most recent common ancestor of the two most closely related species.

PAGE FOR ANSWERING QUESTION 6



ADDITIONAL PAGE FOR ANSWERING QUESTION 6

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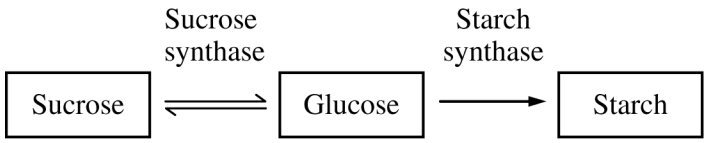


Figure 1. Simplified starch biosynthesis pathway in plants

7. A rice grain is a fruit that encloses a seed. Most of the dry mass of a rice grain is starch. In rice plants, starch is produced by hydrolyzing sucrose and then linking the released glucose molecules together into starch (Figure 1). The optimal temperature range for starch synthase activity in a particular strain of rice is 27°C–30°C. The optimal temperature range for sucrose synthase in the strain is 30°C–35°C.

   **Describe** how temperatures above 35°C most likely affect the structure and function of the starch synthase in the particular strain. Using the information provided, **predict** the most likely consequences to starch content in mature rice grains if the rice is grown in an area where the average temperature during the growing season is 33°C.

PAGE FOR ANSWERING QUESTION 7

ADDITIONAL PAGE FOR ANSWERING QUESTION 7

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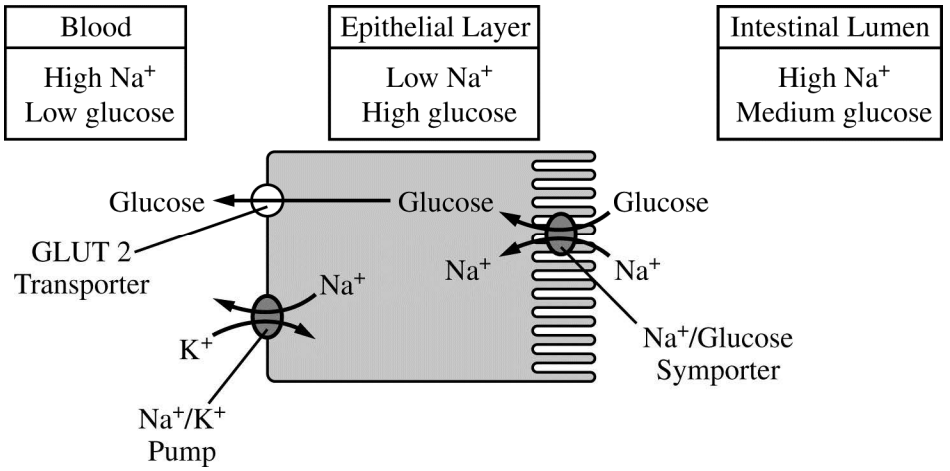


Figure 1. A single cell from the epithelial layer lining the intestine, illustrating movement of glucose and $Na^+$ from the intestinal lumen to the blood

8. Glucose and sodium move from the lumen of the small intestine into the blood via transport proteins in the epithelial cells lining the small intestine (Figure 1). Based on Figure 1, **describe** the direct source of energy used to move glucose into the epithelial cell from the intestinal lumen. **Explain** how this system maximizes glucose absorption from the intestinal lumen into the epithelial cells and from the epithelial cells into the blood.

PAGE FOR ANSWERING QUESTION 8

ADDITIONAL PAGE FOR ANSWERING QUESTION 8

**GO ON TO THE NEXT PAGE.**

**STOP**

**END OF EXAM**

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

---

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

- **MAKE SURE YOU HAVE COMPLETED THE IDENTIFICATION INFORMATION AS REQUESTED ON THE FRONT AND BACK COVERS OF THE SECTION II BOOKLET.**
- **CHECK TO SEE THAT YOUR AP NUMBER LABEL APPEARS IN THE BOX ON THE FRONT COVER.**
- **MAKE SURE YOU HAVE USED THE SAME SET OF AP NUMBER LABELS ON ALL AP EXAMS YOU HAVE TAKEN THIS YEAR.**

# Multiple-Choice and Grid-In Answer Key

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

# Answer Key for AP Biology Practice Exam, Section I

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

Question 121: 3

Question 122: 1/2, 0.5

Question 123: 0.67 through 0.68

Question 124: 0.64 through 0.66

Question 125: –8.8 through –8.3

# Free-Response Scoring Guidelines

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

# AP® BIOLOGY
# 2016 SCORING GUIDELINES

## Question 1

In an investigation of the effect of a particular insecticide on plant growth and development, researchers established 20 test plots containing mature *Haplopappus squarrosus* shrubs. *H. squarrosus* is pollinated by certain species of insects and is eaten by other species of insects. Ten test plots were sprayed with the water-soluble insecticide, and ten test plots were sprayed with water only. The researchers recorded the numbers of plants or plant parts at different life stages in each test plot. The results of the investigation are shown in the table.

EFFECT OF INSECTICIDE TREATMENT ON PLANT GROWTH AND DEVELOPMENT

| | | Treatment | | |
|---|---|---|---|---|
| | | Water Spray | Insecticide Spray | |
| Plant Life Stage | Plant or Plant Part | Mean Density $\pm 2SE_{\bar{x}}$ (number/m$^2$) | | P-values* |
| Flowering | Flowers | 8,220 ±360 | 9,490±1900 | ≥0.05 |
| Seed Formation | Immature Seeds | 2,440±78 | 3,100±480 | ≥0.05 |
| Seed Maturation | Mature seeds | 60±44 | 1,200±1020 | ≤0.001 |
| Seedling Development | Seedlings | 1.4±0.4 | 33.1±15 | ≤0.01 |
| *based on an analysis of variance (ANOVA) test | | | | |

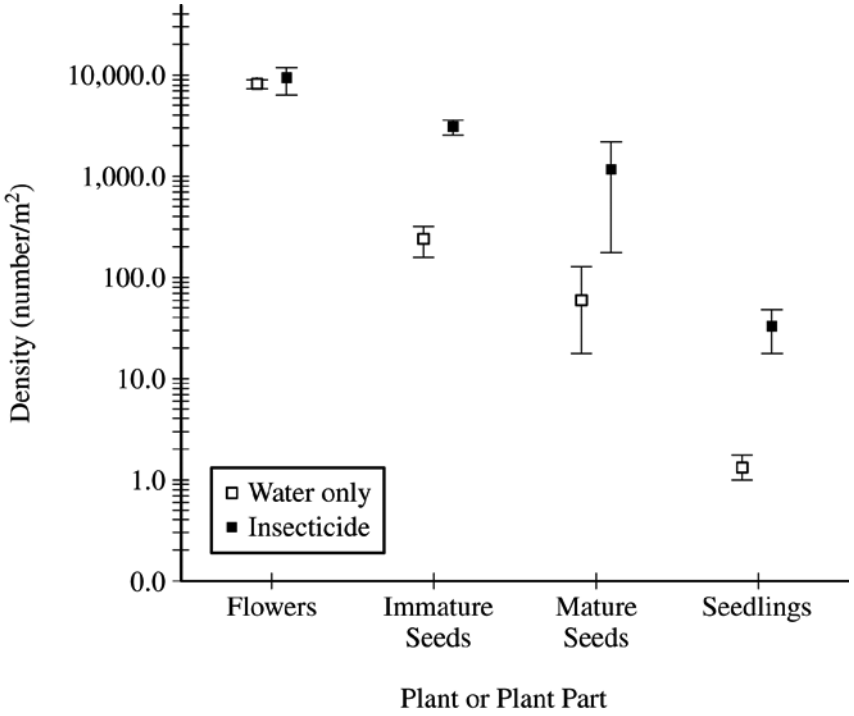


Figure 1. Student-constructed graph of data with a plotting error

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# 2016 SCORING GUIDELINES

## Question 1 (continued)

(a) **Identify** the control treatment in the original experiment. **Provide reasoning** to support the researcher's decision to not use a set of unsprayed plants as a control. **(2 points)**

**Identification (1 point)**

- The water-only treatment

**Reasoning (1 point)**

- Unsprayed plot would not distinguish between effect of insecticide vs. effect of water
- Water only treatment attributes the effect of the insecticide treatment to the insecticide and not the water

(b) A student incorrectly plotted one value from the table on a graph (Figure 1). **Identify** the error in the student-constructed graph. **Provide reasoning** to support the student's choice of a logarithmic scale on the Y axis. **(2 points)**

**Identify (1 point)**

- The seed formation stage/immature seeds data point from the water only treatment

**Reasoning (1 point)**

- The data span several orders of magnitude
- Enables display of all data on one graph
- Couldn't visually distinguish differences in smaller values if they were plotted on a linear scale

# AP® BIOLOGY
# 2016 SCORING GUIDELINES

## Question 1 (continued)

(c) Using the template provided, **calculate** the percent of plants or plant parts remaining from one life stage to the next life stage. Round your answer to one decimal place. Based on your calculations, **identify** the plant life stage at which the insects have the greatest impact on the life cycle of the plant. **Justify** your answer. **Describe** the most likely interaction between the insects and the plants. **(4 points)**

**Calculation (1 point)**

| Plant Life Stage | Water Spray | Percent Remaining | Insecticide Spray | Percent Remaining |
|---|---|---|---|---|
| Flowering | 8220 | | 9490 | |
| Seed Formation | 2440 | **29.7** | 3100 | **32.7** |
| Seed Maturation | 60 | **2.5** | 1200 | **38.7** |
| Seedling development | 1.4 | **2.3** | 33.1 | **2.8** |

**Identification (1 point)**

- Seed maturation
- Between immature seeds and mature seeds

**Justification (1 point)**

- Seed maturation time point is the only one with large difference in the percent remaining between treatment groups
- Number of mature seeds remaining in water only treatment is much less than number of mature seeds remaining in insecticide spray
- Seed maturation is the first stage where there is a significant difference in numbers of plants/plant parts between the treatment groups

**Description (1 point)**

- Insects must be eating/hurting the developing seeds

(d) In a second experiment, researchers used a different insecticide that affects a different group of insects. In this treatment, the number of seeds formed was greatly reduced compared to the control. Based on this observation, **describe** the most likely interaction between the affected insects and the plants in this experiment. **Justify** your response. **(2 points)**

| **Description (1 point)** | **Justification (1 point)** |
|---|---|
| Insects must be pollinating flowers | When pollination is prevented, seeds do not develop |
| Specific example of a positive/beneficial impact to the plants during seed formation (e.g., remove parasite/herbivore) | Supports how cooperative interaction between insect and plant promotes seed formation |

*Points can only be earned in one row of the table.

# AP® BIOLOGY
# 2016 SCORING GUIDELINES

## Question 2

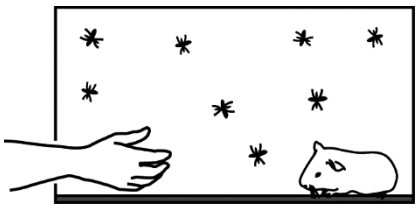


Figure 1. Diagram of the choice chamber used to measure host preference of mosquitoes

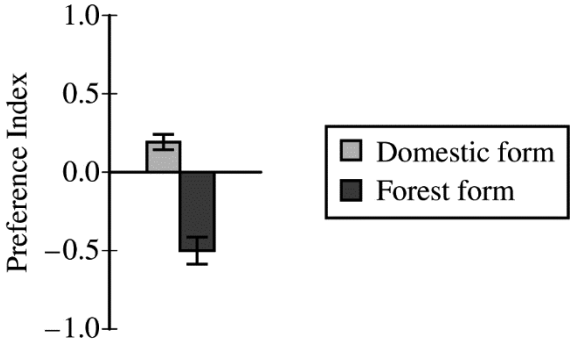



Figure 2. Mean host preference index $\pm 1SE_{\bar{X}}$ of forest and domestic forms of mosquitoes. A positive value indicates preference for a human host, and a negative value indicates preference for a guinea pig host.

The yellow-fever mosquito (*Aedes aegypti*) is a major vector of human disease. In a particular location in Africa, there are two forms of the mosquito. The forest form of the mosquito is black and often lays its eggs in tree holes and pools of water in the forest. The domestic form of the mosquito is brown and prefers to lay its eggs in rainwater collected near human dwellings.

Researchers used a choice chamber (Figure 1) to investigate the host preference of *A. aegypti*. The researchers recorded the number of forest-form and domestic-form mosquitoes that bit human or guinea pig hosts during several ten-minute trials. The researchers used these data to calculate a host-preference index for each form, as shown in Figure 2. Researchers also identified a gene in the mosquitoes, *OR4*, that encodes an olfactory receptor. A volatile odorant, sulcatone, binds to the OR4 receptor. Humans produce higher levels of sulcatone than do guinea pigs.

(a) Based on an analysis of the data, **identify** the preferred host of the forest form and of the domestic form of the mosquito. **(2 points)**

**Identification (2 points)**

- Forest mosquitoes prefer guinea pig
- Domestic mosquitoes prefer human hosts

(b) **Propose a refinement** to the initial experimental design that will rule out the possibility that preference is based on a visual cue. **Propose** a different refinement to the initial experiment to test whether sulcatone is the attractant for the human-preferring form. **(2 points)**

**Refinement: visual (1 point)**

- Use a dark/no light box
- Cover the guinea pig/hand
- Use guinea pig/hand models
- Stop movement of guinea pig/hand
- Blind mosquitoes

## Question 2 (continued)

**Refinement: sulcatone (1 point)**

- Use cotton ball/guinea pig/guinea-pig model soaked in sulcatone vs. control without sulcatone
- Use gloved/covered human hand that prevents odorant molecules from being released
- Remove or alter the OR4 gene in mosquitoes

(c) **Predict** how each of the following mutations in the *OR4* gene would most likely affect the sensitivity of mosquitoes to sulcatone. **Justify** each prediction. **(4 points)**

- A mutation that results in the removal of the intracellular domain of the receptor protein
- A mutation that results in the substitution of a small hydrophobic amino acid for another small hydrophobic amino acid in the ligand-binding site of the receptor protein

| | **Prediction (1 point each mutation; 2 points total)** | **Justification (1 point each mutation; 2 points total)** |
|---|---|---|
| Removal of intracellular domain | Decreased sensitivity/insensitive | Unable to initiate intracellular signal/cascade |
| Substitution in ligand-binding site | No change (in sensitivity) | • Ligand can still bind to receptor<br>• Conformation/shape of ligand-binding domain does not change |
| | Ligand can still bind to receptor | A similar amino acid leads to no/limited change to the structure of the protein |

*other predictions may earn credit when appropriately justified

(d) A researcher proposes that the two forms of mosquitoes are evolving into two different species. **Identify** ONE potential postzygotic isolating mechanism, and **describe** how the isolating mechanism would result in the evolution of the two forms into different species. **(2 points)**

**Identification (1 point)**

- Hybrid inviability
- Hybrid sterility
- Reduced hybrid fitness/hybrid breakdown

**Description (1 point)**

- Maintains reproductive isolation
- Prevents gene flow

# AP® BIOLOGY
# 2016 SCORING GUIDELINES

## Question 3

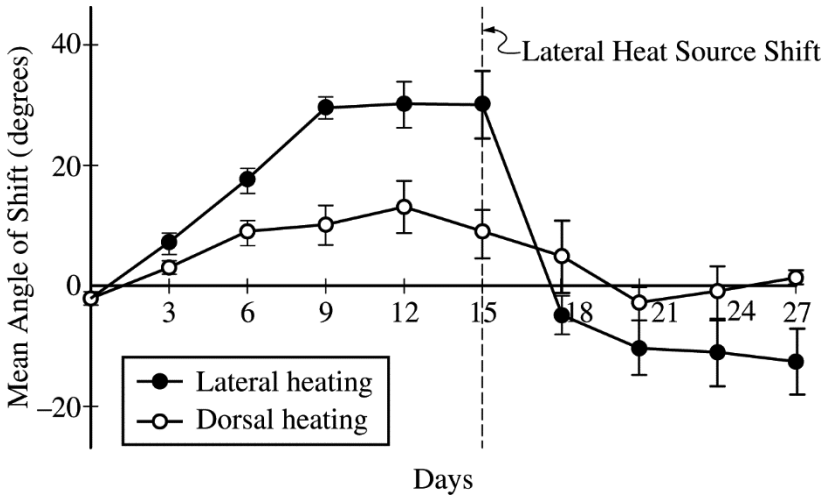



Figure 1. Mean angle of the shift in turtle embryo position following exposure to a directional heat source. The error bars represent $\pm 2SE_{\bar{x}}$.

A certain species of turtle (*Pelodiscus sinensis*) lays its eggs in nests that are buried in the sand. The turtle then leaves the eggs to develop. A researcher claims that turtle embryos are able to shift within their eggs in response to directional thermal cues in the environment. To test the claim, the researcher incubated turtle eggs in containers and used heating pads to deliver heat either to the top of the container (dorsal heating) or to one side of the container (lateral heating). The position of the lateral heat source was switched from one side to the other on day 15. The researcher recorded the shifts in embryo position relative to the initial embryo position in the egg. The results are shown in Figure 1.

(a) **Indicate** whether the researcher's claim that turtle embryos within their eggs respond to thermal cues is supported or not supported. Using the data, **justify** your response. **(2 points)**

**Indication (1 point)**

- The researcher's claim is supported/embryos adjust their position in response to thermal cues

**Justification (1 point)**

- The change in angle following the shift in lateral heat source is statistically significant in the experimental treatment/lateral heating but not in the control treatment/dorsal heating
- Shift in lateral heat source causes a statistically significant shift in the angle of the laterally heated/experimental embryos compared to the shift in the dorsally heated/control embryos
- The mean angle $\pm 2SE_{\bar{x}}$ prior to the shift in lateral heat source does not overlap with mean angle $\pm 2SE_{\bar{x}}$ after the shift in lateral heat source but the means $\pm 2SE_{\bar{x}}$ do overlap in the control

## Question 3 (continued)

(b) The researcher used the dorsal heat treatment as the control. **Propose** a different treatment that would have been another valid control. **(1 point)**

**Proposed control (1 point)**

- No heat source
- Uniform heat source
- Ventral heat source
- Lateral heat source that does not shift

(c) The researcher hypothesizes that when turtle embryos respond to thermal cues they develop more rapidly than do turtle embryos that do not respond to thermal cues. **Describe** ONE potential advantage for turtles having a shorter embryonic period. **(1 point)**

**Description (1 point)**

- Decrease vulnerability to predation
- Decrease exposure to parasitic infections
- Better chance of obtaining resources than nest mates/other species

# AP® BIOLOGY
# 2016 SCORING GUIDELINES

## Question 4

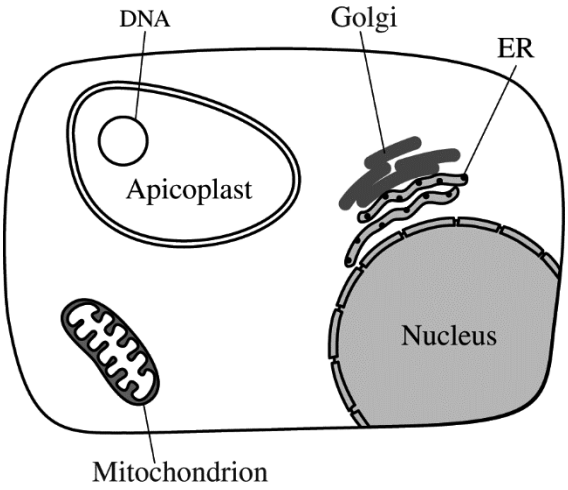



Figure 1. Simplified diagram of cellular structures of *Plasmodium falciparum*

The eukaryotic protozoan parasite *P. falciparum* is the causative agent of malaria. *P. falciparum* cells contain an organelle called the apicoplast (see Figure 1). Apicoplasts synthesize precursors of biomolecules that are required for growth and reproduction of the parasite.

(a) Based on Figure 1, **describe** TWO pieces of evidence a researcher could use to support the claim that apicoplasts evolved from free-living, prokaryotic organisms. **(2 points)**

**Description (2 points maximum)**

- Possesses a double membrane
- Possesses DNA

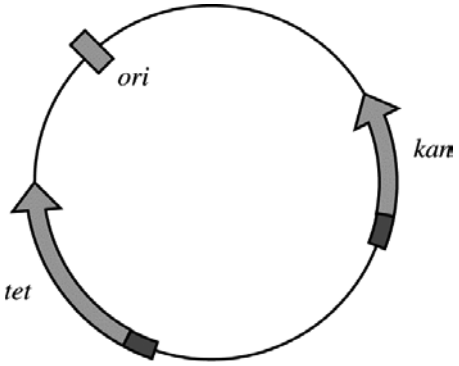
(b) Doxycycline is a drug used to treat malaria and some bacterial infections. Doxycycline binds to the prokaryotic 30S ribosomal subunit and inhibits its function. **Explain** how doxycycline can be an effective treatment for a *P. falciparum* infection in humans. **(2 points)**

**Explanation (2 points maximum)**

- Apicoplasts possess 30S/prokaryotic ribosomes
- Prokaryotic/apicoplast proteins are not synthesized (in presence of doxycycline)

# AP® BIOLOGY
# 2016 SCORING GUIDELINES

## Question 5




pTET-KAN

The *pTET-KAN* plasmid carries an origin of replication (*ori*) and genes conferring resistance to the antibiotics tetracycline (tet) and kanamycin (kan) as represented in the figure. Cultures of *E. coli* bacteria were transformed with the plasmid. To determine the success of the transformation experiment, the bacterial cells were cultured in the presence or absence of tetracycline overnight.

(a) **Predict** the most likely outcome of culturing transformed *E. coli* in the presence of tetracycline. **Justify** your prediction. (**2 points)**

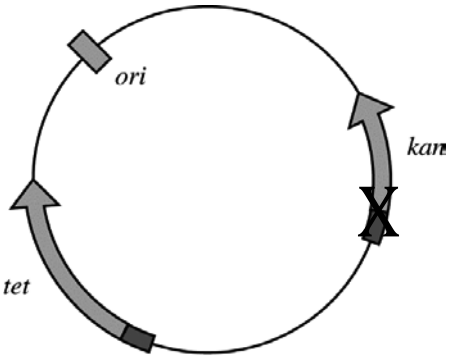
**Prediction (1 point)**

- Cells will reproduce/grow
- Cultures will grow
- Bacterial population will increase in size
- Untransformed cells will not reproduce/grow

**Justification (1 point)**

- Expression of the tet-resistance gene
- Synthesis of tet-resistance protein

(b) Researchers inserted a small fragment of human DNA into the *pTET-KAN* plasmid. Cultures of *E. coli* were transformed with the modified plasmid. The transformed bacterial cells were able to survive in the presence of tetracycline but were unable to survive in the presence of kanamycin. **Draw** an X on the plasmid template provided below to indicate where the human DNA fragment was most likely inserted. **Justify** your placement of the inserted human DNA. **(2 points)**




pTET-KAN

**Identification (1 point)**

- make an X in the area within the kan gene or kan promoter

**Justification (1 point)**

- They must not have had an intact *kan* gene/promoter
- The human DNA disrupted the *kan* gene/promoter

# AP® BIOLOGY
# 2016 SCORING GUIDELINES

## Question 6

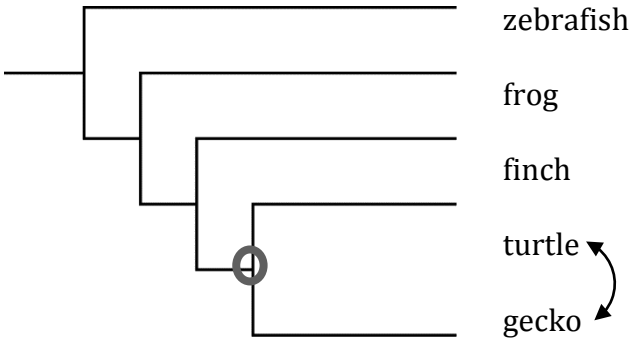
NUMBER OF DIFFERENCES IN THE FIRST 60 AMINO ACIDS OF THE NEUROMODULIN PROTEIN ISOLATED FROM FIVE SPECIES

| | Finch | Gecko | Turtle | Frog | Zebra fish |
|---|---|---|---|---|---|
| Finch | 0 | 2 | 2 | 6 | 10 |
| Gecko | | 0 | 1 | 7 | 11 |
| Turtle | | | 0 | 7 | 11 |
| Frog | | | | 0 | 13 |
| Zebra fish | | | | | 0 |

Neuromodulin is an essential protein that is highly conserved among vertebrates. Researchers compared the first 60 amino acids of the neuromodulin protein from each of five different species. The results are shown in the table above.

Based on the data in the table, **construct** a cladogram on the template provided to represent the evolutionary relatedness of the five species. Using the data, **justify** the placement of the zebra fish on the cladogram. On the cladogram, circle the position of the most recent common ancestor of the two most closely related species. **(3 points)**

**Construction/Circle (2 points)**




- Correct placement of organisms on the tree: zebrafish, frog, finch, turtle, gecko (from top to bottom; turtle and gecko can be reversed)
- Circle the node that appears furthest to the right

**Justification (1 point)**

- The zebrafish has the greatest number of differences (in neuromodulin sequence) compared to the other organisms

# AP® BIOLOGY
# 2016 SCORING GUIDELINES

## Question 7

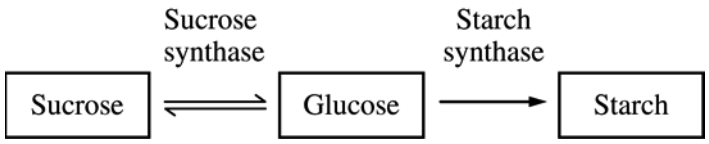



Figure 1. Simplified starch biosynthesis pathway in plants

A rice grain is a fruit that encloses a seed. Most of the dry mass of a rice grain is starch. In rice plants, starch is produced by hydrolyzing sucrose and then linking the released glucose molecules together into starch (Figure 1). The optimal temperature range for starch synthase activity in a particular strain of rice is 27°C–30°C. The optimal temperature range for sucrose synthase in the strain is 30°C–35°C.

**Describe** how temperatures above 35°C most likely affect the structure and function of the starch synthase in the particular strain. Using the information provided, **predict** the most likely consequences to starch content in mature rice grains if the rice is grown in an area where the average temperature during the growing season is 33°C. **(3 points)**

**Description (2 points; 1 point per row)**

| | |
|---|---|
| Structure | • Starch synthase conformation/shape will change<br>• Enzyme will become (partially) denatured |
| Function | The activity of the enzyme will decrease |

**Prediction (1 point)**

- Starch content will be less than it would be at optimal temperatures

# AP® BIOLOGY
# 2016 SCORING GUIDELINES

## Question 8

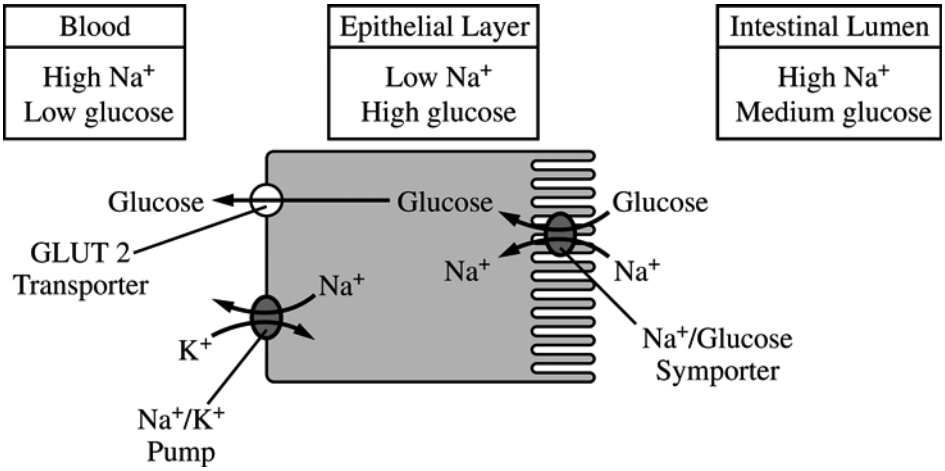



Figure 1. A single cell from the epithelial layer lining the intestine illustrating movement of glucose and $Na^+$ from the intestinal lumen to the blood

Glucose and sodium move from the lumen of the small intestine into the blood via transport proteins in the epithelial cells lining the small intestine (Figure 1). Based on Figure 1, **describe** the direct source of energy used to move glucose into the epithelial cell from the intestinal lumen. **Explain** how this system maximizes glucose absorption from the intestinal lumen into the epithelial cells and from the epithelial cells into the blood. **(3 points)**

### Description (1 point)

- Energy from the sodium gradient

### Explanation (2 points maximum)

- The $Na^+/K^+$ pump maintains the sodium concentration gradient and allows for the cotransport of glucose
- The symport/inflow of glucose maintains a glucose concentration gradient between the epithelial cells and the blood and allows for (facilitated) diffusion of glucose
- The microvilli/folds on the lumen side of the epithelial cell provide more surface area for uptake of glucose into the epithelial cell

## Scoring Worksheet

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

# 2016 AP Biology Scoring Worksheet

**Section I: Multiple Choice and Grid-In**

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

**Section II: Free Response**

| | | | | |
|---|---|---|---|---|
| Question 1 | _____ (out of 10) | × 1.5000 = | _____ (Do not round) | |
| Question 2 | _____ (out of 10) | × 1.5000 = | _____ (Do not round) | |
| Question 3 | _____ (out of 4) | × 1.4285 = | _____ (Do not round) | |
| Question 4 | _____ (out of 4) | × 1.4285 = | _____ (Do not round) | |
| Question 5 | _____ (out of 4) | × 1.4285 = | _____ (Do not round) | |
| Question 6 | _____ (out of 3) | × 1.4285 = | _____ (Do not round) | |
| Question 7 | _____ (out of 3) | × 1.4285 = | _____ (Do not round) | |
| Question 8 | _____ (out of 3) | × 1.4285 = | _____ (Do not round) | |
| | | Sum = | _____ Weighted Section II Score (Do not round) | |

**Composite Score**

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

AP Score Conversion Chart
Biology

| Composite Score Range | AP Score |
|---|---|
| 86-120 | 5 |
| 68-85 | 4 |
| 49-67 | 3 |
| 30-48 | 2 |
| 0-29 | 1 |

# Question Descriptors and Performance Data

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

# 2016 AP Biology

# Question Descriptors and Performance Data

## Multiple-Choice Questions

| Question | Learning Objectives | Essential Knowledge | Science Practice | Key | % Correct |
|---|---|---|---|---|---|
| 1 | 4.26 | 4C3 | 6.4 | C | 66 |
| 2 | 1.16 | 1B1 | 6.1 | B | 77 |
| 3 | 3.25\|3.24 | 3C1 | 1.1\|6.4 | A | 84 |
| 4 | 4.21 | 4B4 | 6.4 | A | 87 |
| 5 | 4.19 | 4B3 | 5.2 | D | 80 |
| 6 | 2.24\|4.18 | 2D1\|4B2 | 5.1\|1.4 | D | 94 |
| 7 | 2.24\|4.15 | 2D1\|4A6 | 5.1\|1.4 | A | 76 |
| 8 | 4.11 | 4A5 | 1.4 | A | 63 |
| 9 | 4.21 | 4B4 | 6.4 | B | 94 |
| 10 | 3.40 | 3E1 | 5.1 | D | 80 |
| 11 | 3.12 | 3A3 | 1.1\|7.2 | D | 76 |
| 12 | 3.29 | 3C2\|3C3 | 6.2 | C | 76 |
| 13 | 1.24 | 1C2 | 7.2 | A | 63 |
| 14 | 1.24 | 1C2 | 7.2 | C | 72 |
| 15 | 1.26 | 1C3 | 5.3 | B | 90 |
| 16 | 1.22 | 1C2 | 6.4 | A | 67 |
| 17 | 2.23 | 2D1 | 4.2 | A | 73 |
| 18 | 3.31\|3.36 | 3D1\|3D3 | 7.2\|1.5 | A | 56 |
| 19 | 2.10 | 2B1 | 1.4 | C | 70 |
| 20 | 2.23 | 2D1 | 4.2 | C | 74 |
| 21 | 3.26 | 3C1 | 7.2 | A | 71 |
| 22 | 1.32 | 1D2 | 4.1 | B | 65 |
| 23 | 1.18 | 1B2 | 5.3 | A | 76 |
| 24 | 2.24\|2.32 | 2D1\|2E1 | 5.1\|1.4 | A | 85 |
| 25 | 2.3 | 2A1 | 6.4 | B | 77 |
| 26 | 2.24 | 2D1 | 5.1 | C | 62 |
| 27 | 1.2 | 1A1 | 2.2 | A | 50 |
| 28 | 3.22 | 3B2 | 6.2 | D | 63 |
| 29 | 3.15 | 3A4 | 6.5 | C | 50 |
| 30 | 3.13 | 3A3 | 3.1 | C | 39 |
| 31 | 4.4 | 4A2 | 6.4 | D | 48 |
| 32 | 3.23 | 3B2 | 1.4 | B | 74 |
| 33 | 2.9 | 2A3 | 1.1 | B | 83 |
| 34 | 2.24 | 2D1 | 5.1 | C | 62 |
| 35 | 2.22 | 2D1 | 1.3\|3.2 | A | 66 |
| 36 | 2.22 | 2D1 | 1.3\|3.2 | D | 69 |
| 37 | 2.22\|4.14 | 2D1\|4A6 | 1.3\|3.2\|2.2 | C | 71 |
| 38 | 3.37 | 3D4 | 6.1 | C | 53 |

# 2016 AP Biology

# Question Descriptors and Performance Data

| Question | Learning Objectives | Essential Knowledge | Science Practice | Key | % Correct |
|---|---|---|---|---|---|
| 39 | 3.17\|3.16 | 3A4 | 1.2\|6.3 | B | 52 |
| 40 | 1.17 | 1B2 | 3.1 | C | 36 |
| 41 | 3.49 | 3E2 | 1.1 | A | 50 |
| 42 | 2.27 | 2D2 | 7.1 | B | 54 |
| 43 | 2.13 | 2B3 | 6.2 | C | 44 |
| 44 | 4.2 | 4A1 | 1.3 | A | 55 |
| 45 | 2.15 | 2C1 | 6.1 | D | 48 |
| 46 | 3.33 | 3D1 | 1.4 | C | 55 |
| 47 | 2.18 | 2C1 | 6.4 | B | 43 |
| 48 | 3.43 | 3E2 | 6.2\|7.1 | B | 43 |
| 49 | 1.13 | 1A4 | 1.1 | B | 45 |
| 50 | 1.1 | 1A1 | 1.5 | C | 49 |
| 51 | 3.4 | 3A1 | 1.2 | C | 37 |
| 52 | 3.16 | 3A4 | 6.3 | D | 38 |
| 53 | 1.6 | 1A3 | 2.1\|1.4 | A | 50 |
| 121 | 1.18 | 1B2 | 5.3 | 3 | 83 |
| 122 | 3.14 | 3A3 | 2.2 | 1/2, 0.5 | 35 |
| 123 | 1.6 | 1A3 | 1.4 | 0.67 – 0.68 | 38 |
| 124 | 4.19\|4.27 | 4B3\|4C4 | 5.2\|6.4 | 0.64 – 0.66 | 33 |
| 125 | 2.12 | 2B2 | 1.4 | -8.8 – -8.3 | 15 |

## Free-Response Questions

| Question | Learning Objective | Essential Knowledge | Science Practice | Mean Score |
|---|---|---|---|---|
| 1 | 2.23\|2.24\|4.11\|4.12\|4.13\|4.15 | 2D1\|4A5\|4A6 | 4.2\|5.1\|7.2\|1.4\|2.2\|6.4 | 3.80 |
| 2 | 1.22\|1.25\|2.22\|2.23\|2.24\|3.24\|4.3 | 1C2\|1C3\|2D1\|3C1\|3D4\|4A1 | 6.4\|1.2\|1.3\|3.2\|4.2\|5.1\|7.2\|6.1 | 4.33 |
| 3 | 2.2\|2.24\|2.32\|2.35\|2.37 | 2A1\|2D1\|2E1\|2E2 | 6.1\|5.1\|1.4\|4.2\|7.2 | 2.26 |
| 4 | 1.16\|1.15\|4.6\|4.5 | 1B1\|4A2 | 6.1\|7.2\|1.4\|6.2 | 1.12 |
| 5 | 3.25\|3.24\|3.26\|3.28 | 3C1\|3C2 | 1.1\|6.4\|7.2\|6.2 | 1.10 |
| 6 | 1.13\|1.19\|1.20 | 1A4\|1B1\|1B2\|1C1 | 1.1\|2.1\|6.1\|5.1 | 1.05 |
| 7 | 2.3\|2.28\|4.17 | 2A1\|2D3\|4B1 | 6.4\|1.4\|5.1 | 0.97 |
| 8 | 2.11\|2.12 | 2B1\|2B2 | 1.1\|7.1\|7.2\|1.4 | 0.52 |

# AP Biology

### The College Board

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