

# RELEASED EXAM

1999

## AP<sup>®</sup> Biology

### CONTAINS:

- Multiple-Choice Questions and Answer Key
- Free-Response Questions, Scoring Guidelines, and Sample Student Responses with Commentary
- Statistical Information about Student Performance on the 1999 Exam

The logo for the Advanced Placement Program, consisting of the letters 'AP' in a bold, italicized, sans-serif font. The letters are dark with a light-colored shadow or outline, giving them a three-dimensional appearance.

*Advanced Placement Program<sup>®</sup>*



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## **The 1999 AP<sup>®</sup> Examination in Biology**

### **Contains:**

- Multiple-Choice Questions and Answer Key
- Free-Response Questions, Scoring Guidelines, and Sample Student Responses with Commentary
- Statistical Information about Student Performance on the 1999 Exam

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# Chapter I

## The AP<sup>®</sup> Process

- Who Develops the AP Biology Exam?
- How Is the Exam Developed?
  - Section I
  - Section II
- Question Types
  - Multiple Choice
  - Free Response
- Scoring the Exam
  - Who Scores the AP Biology Exam?
  - Ensuring Accuracy
  - How the Scoring Guidelines Are Created and Applied
  - Maintaining the Scoring Guidelines
- Preparing Students for the Exam
- Teacher Support

This chapter will give you a brief overview of what goes on behind the scenes during the development and grading of the AP Biology Exam. You can find more detailed information in the “Technical Corner” of the AP website ([www.collegeboard.org/ap](http://www.collegeboard.org/ap)).

### Who Develops the AP Biology Exam?

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The AP Biology Development Committee, working with content experts at Educational Testing Service (ETS), is responsible for creating the exam. This Committee that developed the 1999 AP Biology Exam was made up of six teachers from secondary schools, colleges, and universities in different parts of the United States. The members provide different perspectives: AP high school teachers offer valuable advice regarding realistic expectations when matters of content coverage, skills required, and clarity of phrasing are addressed. On the other hand, college and university faculty members ensure that the questions are at the appropriate level of difficulty for an introductory college course in Biology. Each member typically serves for three years.

Another person who aids in the development process is the Chief Faculty Consultant (CFC). The CFC attends every committee meeting to ensure that the free-response questions selected for the exam can be scored reliably. You can find out more about the role of the CFC, and the scoring process in general, on pages 2-4.

### How Is the Exam Developed?

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It takes at least two years to develop each AP Biology Exam. The development process is different for Section I (multiple-choice) and Section II (free-response) sections:

#### Section I

1. Each committee member independently writes a selection of multiple-choice questions based on the course content outline.
2. The Committee convenes to review these draft questions and to make sure that they are accurate and appropriate for a first-year college course in Biology.
3. Most of the multiple-choice questions are pretested in college classes to obtain some estimate of the questions' level of difficulty.
4. The questions that make it through these screening processes are assembled according to test specifications developed by the Committee to parallel an introductory college course. After further editing and checking, these questions comprise Section I of the AP Biology Exam.
5. The desired level of difficulty of the multiple-choice section (about 50% mean as percent of maximum) is achieved by including a variety of questions at different levels of difficulty.

## Section II

1. Individual committee members write a selection of free-response questions based on the course content outline.
2. The Committee reviews and refines draft questions, and determines which will work well for the AP Exam. They consider, for example, whether the questions will offer an appropriate level of difficulty and whether they will elicit answers that allow faculty consultants to discriminate among the responses along a particular scoring scale. An ideal question enables the stronger students to demonstrate their accomplishments while still allowing less advanced students to show the material they have mastered.
3. Four questions are selected that follow the test specifications, with one question that is primarily from Part I of the outline (Molecules and Cells), one from Part II (Heredity and Evolution), and two from Part III (Organisms and Populations). Many questions require students to integrate material from across the course outline, and one or more of the four questions draw upon the objectives of the 12 recommended laboratory activities.
4. In the last stage of development, committee members give approval to a final draft of all multiple-choice and free-response questions. This review takes place several months before the administration of the exam.

## Question Types

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The AP Exam in Biology contains a 90-minute multiple-choice section and a 90-minute free-response section. The two sections are designed to complement each other and to meet the overall course objectives and exam specifications.

**Multiple-choice questions** are especially useful for measuring the breadth of content in the curriculum. In addition, they have three other strengths:

1. They are highly reliable. Reliability, or the likelihood that candidates of similar ability levels taking a different form of the exam will receive the same scores, is controlled more effectively with multiple-choice questions than with free-response questions.

2. They allow the Development Committee to include a selection of questions at various levels of difficulty, thereby ensuring that the measurement of differences in students' achievement is optimized. For AP Exams, the most important distinctions are between students earning the grades of 2 and 3, and 3 and 4. These distinctions are usually best accomplished by using many questions of middle difficulty.
3. They allow the CFC to compare the ability level of the current candidates with those from another year. A number of questions from an earlier exam are included in the current one, thereby allowing comparisons to be made between the scores of the earlier group of candidates and the current group. This information, along with other data, is used by the CFC to establish AP grades that reflect the competence demanded by the Advanced Placement Program, and that compare with grades from previous years.

**Free-response questions** on the AP Biology Exam require students to use their analytical and organizational skills to formulate cogent answers. They also allow students:

1. To relate different content areas as they formulate a complete response to a Biology question.
2. To present novel, yet correct responses.
3. To demonstrate their mastery of quantitative aspects of biology.

Free-response and multiple-choice questions are analyzed both individually and collectively after each administration, and the conclusions are used to improve the following year's exam.

## Scoring the Exam

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### Who Scores the Biology Exam?

The people who score the free-response section of the AP Biology Exam are known as faculty consultants or "readers." These faculty consultants are experienced biology instructors who teach the AP course in a high school or the equivalent course at a college or university. Great care is taken to get a broad and balanced group of teachers. Among the factors consid-

ered before appointing someone to the role are the teacher's years of teaching experience and his or her expertise, gender, and ethnicity as well as school type (public, private, magnet, etc.), geographic location, and setting (urban, rural, etc.). If you are interested in applying to be a faculty consultant at a future AP Reading, you can complete and submit an online application in the "Teachers" section of the AP website ([www.collegeboard.org/ap](http://www.collegeboard.org/ap)), or request a printed application by calling (609) 406-5384.

During the second week of June 1999, 254 teachers of Biology, about half from colleges and half from high schools, gathered at Clemson University, in Clemson, South Carolina to evaluate more than 81,000 AP Biology Exams. Among these teachers, 37 were invited to serve as "table leaders" and to come to the Reading two days early to help lead the effort. The remaining readers were divided into teams of 6-7 readers each, with each team reporting to one table leader, and the table leaders for each question reporting to one of four question leaders. Under the guidance of the Chief Faculty Consultant (CFC), the question leaders and the table leaders had responsibility for organizing the details of the Reading and conveying information to the faculty consultants in the respective teams.

## Ensuring Accuracy

The primary goal of the scoring process is to have each faculty consultant score his or her set of papers fairly, uniformly, and to the same standard as the other faculty consultants. This is achieved through the creation of detailed scoring guidelines, the thorough training of all faculty consultants, and various "checks and balances" applied throughout the AP Reading.

## How the Scoring Guidelines Are Created

1. Before the AP Reading, the CFC and question leaders prepare drafts of the scoring guidelines (rubrics) for the free-response question. In the case of Biology, an 11-point scale (0-10) was used. A score of 0 means the student received no credit for the problem.
2. The CFC, question leaders, table leaders, and ETS content experts meet at the Reading site a few days before the Reading begins. They review and revise the draft scoring rubrics, and test them by prescoring randomly selected student papers.
3. The tables of faculty consultants who are to read each question meet as a group on the first morning and discuss the scoring rubrics that have been developed. Student papers are again test scored, and the application of the rubrics discussed among readers. If problems or ambiguities become apparent, the scoring guidelines are revised and refined until a final consensus is reached.
4. Once the faculty consultants as a group can apply the standards consistently and without disagreement, they begin reading in teams of two. Each team member scores several papers and then exchanges the examinations for a second reading. Scores and differences in judgment are discussed until agreement is reached, with the question leaders, the table leaders, or the CFC acting as arbitrator when needed.
5. After a team shows consistent agreement on its scores, its members proceed to score individually. Faculty consultants are encouraged to seek advice from each other, the question leaders and table leaders, or the CFC when in doubt about a score. A student response that is problematic receives multiple readings and evaluations.

## Maintaining the Scoring Guidelines

A potential problem is that a faculty consultant could give an answer a higher or lower score than it deserves because the same student has performed well or poorly on other questions. The following steps are taken to prevent this so-called "halo effect."

- Each question is read by a different faculty consultant and the student's identification information is covered. Using these practices permits each reader to evaluate free-response answers without being prejudiced by knowledge about individual candidates.

- No marks of any kind are made on the students' papers. The scores are recorded by the readers on a scannable form, identified only by the student's AP number.

Here are some other methods that help ensure that everyone is adhering closely to the scoring guidelines:

- The entire group discusses pregraded papers each morning and as necessary during the day.
- Table leaders re-read (back read) a sample of the student papers from each of the readers in that leader's team. This approach allows each leader to guide his or her readers toward appropriate and consistent interpretations of the rubrics.
- Faculty consultants are paired, so that every reader has a partner to check consistency and to discuss problem cases with; table leaders are also paired up to help each other on questionable calls.
- The CFC and the question leaders monitor use of the full range of the scoring scale for the group and for each faculty consultant by checking daily graphs of score distributions, and read randomly selected papers to check for scoring consistency.

## The Course

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The AP Biology course is designed to be the equivalent of a college introductory biology course usually taken by biology majors during their first year. The two main goals of an AP Biology course are to help students develop a conceptual framework for modern biology and to help students gain an appreciation of science as a process. The ongoing information explosion in biology makes these goals even more challenging. Primary emphasis in an AP Biology course should be on developing an understanding of concepts rather than on memorizing terms and technical details. Essential to this conceptual understanding are the following: a grasp of science as a process rather than as an accumulation of facts; personal experience in scientific inquiry; recognition of unifying themes that integrate the major topics of biology; and application of biological knowledge and critical thinking to environmental and social concerns.

Biology is interdisciplinary; it embraces a wide variety of topics from different areas of study. Yet there

are several major unifying constructs, or themes, that cut across the many topics included in the study of Biology. The following themes provide a foundation for the structure of the AP Biology course: I. Science as a Process; II. Evolution; III. Energy Transfer; IV. Continuity and Change; V. Relationship of Structure to Function; VI. Regulation; VII. Interdependence in Nature; and VIII. Science, Technology, and Society. Themes can be applied across the entire curriculum and serve to unify the course.

## Preparing Students for the Exam

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As outlined in the *Advanced Placement Program Course Description* in Biology, the course focuses on three main content areas: I. Molecules and Cells, 25 percent; II. Heredity and Evolution, 25 percent; and III. Organisms and Populations, 50 percent. The percentage goals should serve as a guide for designing an AP Biology course and may be used to apportion the time devoted to each category. The examination is constructed using the percentage goals as guidelines for question distribution.

The free-response portion of the examination asks the students to organize answers to broad questions, thereby demonstrating reasoning and analytical skills, as well as an ability to synthesize material from several sources into a cogent and coherent essay. In order to prepare for such examination questions, students should practice writing free-response answers whenever appropriate during the course.

As outlined in the *Course Description* booklet, laboratory experience is essential to any AP Biology course. Since one-fourth to one-third of the credit in comparable college courses is derived from laboratory work, AP courses should likewise emphasize laboratory work. The 12 recommended laboratory exercises are as follows:

- Laboratory 1 — Diffusion and Osmosis
- Laboratory 2 — Enzyme Catalysis
- Laboratory 3 — Mitosis and Meiosis
- Laboratory 4 — Plant Pigments and Photosynthesis
- Laboratory 5 — Cell Respiration
- Laboratory 6 — Molecular Biology



- Laboratory 7 — Genetics of Organisms
- Laboratory 8 — Population Genetics and Evolution
- Laboratory 9 — Transpiration
- Laboratory 10 — Physiology of the Circulatory System
- Laboratory 11 — Animal Behavior
- Laboratory 12 — Dissolved Oxygen and Aquatic Primary Productivity

The objectives for these laboratory exercises are listed in the *Course Description* booklet as well as in the *AP Biology Laboratory Manual*, and may be tested in both the multiple-choice and the free-response section of the exam. Results of the survey questions that follow the exam show that students who have done labs that address the objectives of the 12 recommended laboratories perform better on the examination.

## Teacher Support

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There are a number of resources available to help teachers prepare their students — and themselves — for the AP course and exam.

**AP workshops and summer institutes.** New and experienced teachers are invited to attend workshops and seminars to learn the rudiments of teaching an AP course as well as the latest in each course's expectations. Sessions of one day to two weeks in length are held year-round. Dates, locations, topics, and fees are available from the College Board's Regional Offices (see the inside front cover of this booklet), in the publication *Graduate Summer Courses and Institutes*, or in the "Teachers" section of our website (see below).

### **AP's corner of College Board Online®.**

Up-to-date AP information is available via CBO at [www.collegeboard.org](http://www.collegeboard.org). Or, you can go directly to AP at [www.collegeboard.org/ap](http://www.collegeboard.org/ap). From there, you can enter the "Teachers" section, which includes a comprehensive list of FAQs; a searchable AP workshop and Summer

Institute database; the latest free-response questions and scoring guidelines; multiple-choice questions; and information about how teachers can join an online discussion group in their subject. One of our newer features is a behind-the-scenes look at who creates the courses and exam; the AP Reading and grading process; the validity and reliability procedures used; and data on student performance. Because of CBO's dynamic nature, and the difficulty of describing it in print, we encourage you to go online and see for yourself what's there.

**Online discussion groups.** The AP Program has developed an interactive online mailing list for each AP subject. Many AP teachers find this free resource to be an invaluable tool for sharing ideas with colleagues on syllabi, course texts, teaching techniques, and so on, and for discussing other AP issues and topics as they arise. To find out how to subscribe, go to the "Teachers" section of our website.

**AP publications and videos.** See the Appendix for descriptions of a variety of useful materials for teachers. Of particular interest is the publication that complements this Released Exam — the Packet of 10. Teachers can use these multiple copies of the 1999 AP Biology Exam, which come with blank answer sheets, to simulate a national administration in their classroom.

**AP videoconferences.** Several videoconferences are held each year so that AP teachers can communicate via fax or telephone with the high school and college teachers who develop AP courses and exams. Schools that participate in the AP Program are notified of the time, date, and subject of the videoconference in advance. Or, you can contact your Regional Office for more information. Videotapes of each conference are available shortly after the event; see the Appendix for ordering information.

## Chapter II

# The 1999 AP Biology Examination

- Exam Content and Format
- Purpose of the Exam
- Giving a Practice Exam
- Instructions for Administering the Exam
- Blank Answer Sheet
- The Exam

### Exam Content and Format

The 1999 AP Biology Exam contained questions from all the major content areas in both the 120-question multiple-choice<sup>1</sup> and the 4-question free-response sections. The content areas are:

- I. Molecules and Cells, 25 percent;
- II. Heredity and Evolution, 25 percent; and
- III. Organisms and Populations, 50 percent.

The free-response section contributed 40 percent to the composite score, and the multiple-choice section contributed 60 percent.

The scoring guidelines for the free-response questions, and sample student responses, can be found in Chapter III.

Section of Exam	Time Allotted	Number of Questions	Type of Questions	% of Composite Score
I	90 Minutes	120	Multiple Choice	60
II	90 Minutes	4	Free Response (includes at least one based on the laboratory objectives)	40

<sup>1</sup>One multiple-choice question was not scored for statistical reasons.

## Purpose of the Exam

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The purpose of the AP Biology Exam is to allow students to demonstrate mastery of the concepts and techniques of modern Biology at the level of an introductory college course.

The AP Biology course is designed to be taken by students after the successful completion of a first course in both high school biology and high school chemistry. It aims to provide students with the conceptual framework, factual knowledge, and analytical skills necessary to deal critically with the rapidly changing science of biology.

After showing themselves to be qualified on the AP Examination, some students, as college freshmen, are permitted to undertake upper-level courses in biology or to register for courses for which biology is a prerequisite. Other students may have fulfilled a basic requirement for a laboratory-science course and will be able to undertake other courses to pursue their majors. Students who receive neither credit nor placement will nonetheless have gained important experience and confidence with college-level work.

## Giving a Practice Exam

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The following pages contain the instructions, as printed in the 1999 *Coordinator's Manual*, for administering the AP Biology Exam, and copies of the blank answer sheet and the 1999 Biology Exam. By using these instructions and the released exam to test your students, you can create an exam situation that closely resembles a national administration. If you choose to test your students in this manner, read only the directions in the boxes to the students; all other instructions are for the person administering the test and need not be read aloud. Some instructions, such as those referring to the date, the time, and page numbers, are no longer relevant; please ignore them.

Another publication that you might find useful is the "Packets of 10," ten copies of the 1999 AP Biology Exam, each with a blank answer sheet. For ordering information, see the Appendix.

**IMPORTANT**

For regular administrations, read ALL of the boxed instructions below **except** for the box marked for administrations using an alternate form of the exam.

For administrations using an alternate form of the exam, read ALL of the boxed instructions below **except** for those marked specifically for the May 19th administration. If these instructions are being used for a late administration, all days, dates, and times to be read aloud should be adjusted as necessary.

The regular administration of this examination includes survey questions. The time allowed for these survey questions is in addition to the actual test-taking time.

Complete the general instructions beginning on page 34. Then say:

**It is Wednesday morning, May 19, and you will be taking the AP Biology Exam. Print your name, last name first, on the front cover of the unsealed Section I booklet and read the directions on the back of the booklet. When you have finished, look up. . . .**

**Work only on Section I until time is called. Do not open the Section II package until you are told to do so. Remember, when you come to the end of the multiple-choice questions, there will be answer ovals left on your answer sheet. Scratch paper is not allowed, but you may use the margins in the Section I booklet. Only No. 2 pencils may be used to mark your answers on Section I. Are there any questions?**

Answer all questions regarding procedure. When you are ready to begin the exam, note the time here \_\_\_\_\_. Then say:

**Open your Section I booklet and begin. You have 90 minutes for this section of the exam.**

Allow 90 minutes. Note the time you will stop here \_\_\_\_\_. While the candidates are working on Section I, you and your proctors should make sure they are marking answers on their answer sheets in pencil and are not looking at their Section II booklets.

After 90 minutes, say:

**Stop working. . . .**

**AT THE MAY 19TH ADMINISTRATION ONLY, SAY:**

**Turn to page 32 in your exam booklet. Answer questions 121 to 135. These are survey questions and will not influence your examination grade. You may not go back at this time to work on any of the previous questions.**

Give students approximately 3 minutes to answer the survey questions. Then say:

**Close your exam booklet and keep it closed on your desk. Do not insert your answer sheet in the booklet. . . . I will now collect the answer sheets.**

After you have collected an answer sheet from every candidate, say:

**Seal the Section I booklet with the three seals provided. Peel each seal from the backing sheet and press it on the front cover so it just covers the area marked "PLACE SEAL HERE." Fold it over the open edge and press it to the back cover. Use one seal for each open edge. Be careful not to let the seals touch anything except the marked areas. . . .**

Collect the sealed Section I exam booklets. Be sure you receive one from every candidate; then give your break instructions. A 5- to 10-minute break is permitted. Students may talk, move about, or leave the room together to get a drink of water or go to the rest room (see "Breaks During the Examination").

Give your break instructions. Then say:

**Testing will resume at \_\_\_\_\_.**

After the break, say:

**Open the package containing your Section II booklet. Turn to the back cover of the booklet, and read the instructions at the upper left. . . . Using a pen with black or dark-blue ink, print your identification information in the boxes. . . . Detach the perforation at the top. . . . Fold the flap down, and moisten and press the glue strip firmly along the entire lower edge. . . . Your identification information should now be covered and will not be known by those scoring your answers.**

**Read the instructions at the upper right of the back cover.**

**AT THE MAY 19TH  
ADMINISTRATION ONLY, SAY:**

Take one AP number label from the center of your Candidate Pack and place the label in the AP number box at the top of the page. If you do not have number labels left, copy your number from the front cover of your Candidate Pack into the box.

**AT AN ADMINISTRATION USING AN  
ALTERNATE FORM OF THE EXAM ONLY, SAY:**

Print your initials in the three boxes provided . . . Next, take two AP number labels from the center of your Candidate Pack and place them in two of the boxes, one below the instructions and one to the left. If you don't have number labels left, copy your number from the front cover of your Candidate Pack into the boxes.

Item 5 [Item 6 for alternate administrations] provides you with the option of giving permission to Educational Testing Service to use your free-response materials for educational research and instructional purposes. Your name would not be used in connection with the free-response materials. Read the statement and answer either "yes" or "no." . . . Are there any questions?

Answer all questions regarding procedure. Then say:

If you will be taking another AP Examination, I will collect your Candidate Pack. You may keep your Candidate Pack if this is your last or only AP Examination.

Collect the Candidate Packs. Then say:

Read the directions for Section II on the back of your booklet. Look up when you have finished. . . . Are there any questions?

Answer all questions regarding procedure. Then say:

Suggested times for the questions in Section II appear on the back cover of your exam booklet. They will not be announced. You may proceed freely from one question to the next. You are responsible for pacing yourself.

If you need more paper, raise your hand. Are there any questions?

Answer all questions regarding procedure. Then say:

Open the Section II booklet.

**AT THE MAY 19TH  
ADMINISTRATION ONLY, SAY:**

Tear out the green insert in the center of the booklet. . . . Print your name, teacher, and school in the upper left-hand corner of the insert. I will be collecting this insert at the end of the administration. It will be returned to you at a later date by your teacher.

You may use the blank areas in your green insert for scratch paper, but write your actual answers on the lined pages in the Section II booklet.



When you are ready to begin the exam, note the time here \_\_\_\_\_. Then say:

Begin work on Section II. You have 90 minutes for this section of the exam.



Allow 90 minutes. Note the time you will stop here \_\_\_\_\_. You and your proctors should check to be sure all candidates are writing their answers in the Section II booklets.

After 90 minutes, say:

Stop working. Close your Section II booklet and keep it closed on your desk. I will now collect your booklets. Remain in your seats, without talking, while the exam materials are being collected. You will receive your grade reports by mid-July and grades will be available by phone beginning July 1st.

Collect the Section II booklets and the green inserts. Be sure you have one of each from every candidate. Check the back of each Section II booklet to make sure the candidate's AP number appears in the box (two boxes for alternate administrations). The green inserts must be stored securely for no less than 48 hours (2 school days) after they are collected. After the 48-hour holding time, the inserts may be given to the appropriate AP teacher(s) for return to the students. (The alternate form of the examination does not have an insert.)

**When all examination materials have been collected, dismiss the candidates.**

Fill in the necessary information for the Biology Examination on the S&R Form. Alternate exams should be recorded on their respective line on the S&R Form. Put the exam materials in locked storage until they are returned to ETS in one shipment after your school's last administration. See "Activities After the Exam."







**Q. THIS SECTION IS FOR THE SURVEY QUESTIONS IN THE CANDIDATE PACK. (DO NOT PUT RESPONSES TO EXAM QUESTIONS IN THIS SECTION.) BE SURE EACH MARK IS DARK AND COMPLETELY FILLS THE OVAL.**

- 1 (A) (B) (C) (D) (E)  
2 (A) (B) (C) (D) (E)  
3 (A) (B) (C) (D) (E)

- 4 (A) (B) (C) (D) (E)  
5 (A) (B) (C) (D) (E)

**DO NOT COMPLETE THIS SECTION UNLESS INSTRUCTED TO DO SO.**

**R.** If this answer sheet is for the French Language, French Literature, German Language, Spanish Language, or Spanish Literature Examination, please answer the following questions. (Your responses will not affect your grade.)

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

**INDICATE YOUR ANSWERS TO THE EXAM QUESTIONS IN THIS SECTION. IF A QUESTION HAS ONLY FOUR ANSWER OPTIONS, DO NOT MARK OPTION (E). YOUR ANSWER SHEET WILL BE SCORED BY MACHINE. USE ONLY NO. 2 PENCILS TO MARK YOUR ANSWERS ON PAGES 2 AND 3 (ONE RESPONSE PER QUESTION). AFTER YOU HAVE DETERMINED YOUR RESPONSE, BE SURE TO COMPLETELY FILL IN THE OVAL CORRESPONDING TO THE NUMBER OF THE QUESTION YOU ARE ANSWERING. STRAY MARKS AND SMUDGES COULD BE READ AS ANSWERS, SO ERASE CAREFULLY AND COMPLETELY. ANY IMPROPER GRIDDING MAY AFFECT YOUR GRADE.**

- 1 (A) (B) (C) (D) (E)  
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FOR QUESTIONS 76-151, SEE PAGE 3.

**DO NOT WRITE IN THIS AREA.**



BE SURE EACH MARK IS DARK AND COMPLETELY FILLS THE OVAL. IF A QUESTION HAS ONLY FOUR ANSWER OPTIONS, DO NOT MARK OPTION E.

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DO NOT WRITE IN THIS AREA.



AREA 3 - COMPLETE THIS AREA ONLY ONCE.

1. YOUR MAILING ADDRESS

YOUR GRADE REPORT WILL BE MAILED TO THIS ADDRESS IN JULY.

USING THE ABBREVIATIONS GIVEN IN YOUR CANDIDATE PACK, FILL ADDRESS INTO BOXES PROVIDED. IF YOUR ADDRESS DOES NOT FIT, SEE ITEM 2 BELOW.

INDICATE A SPACE IN YOUR ADDRESS BY LEAVING A BLANK BOX AND FILLING IN THE CORRESPONDING DIAMOND (X) BELOW THE BOX.

Grid for mailing address with columns for Street, City, State, ZIP OR POSTAL CODE, and 1a. COUNTRY CODE. Includes a list of state abbreviations and a diamond grid for each character position.

3. TELEPHONE

Area Code and Telephone Number grid with columns for Area Code and Telephone Number.

2. If the address gridded above is not complete enough for delivery of your grade report, please fill in this oval and print your complete address below.

Form for complete address including fields for Address, State or Province, City, and Zip or Postal Code.

4. SCHOOL YOU ATTEND

Make sure you have correctly entered your School Code and filled in the appropriate ovals.

Form for school information including School Code, School Name, City, and State.

5. COLLEGE TO RECEIVE YOUR AP GRADES

Using the College Code list in the AP Candidate Pack, indicate the one college that has accepted you and that you plan to attend.

Form for college information including College Code, College Name, City, and State.

## The Exam

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### BIOLOGY

Three hours are allotted for this examination: 1 hour and 30 minutes for Section I, which consists of multiple-choice questions; and 1 hour and 30 minutes for Section II, which consists of essay questions. Section I is printed in this examination booklet. Section II is printed in a separate booklet. No calculators may be used on either section.

#### SECTION I

Time— 1 hour and 30 minutes

Number of questions— 120

Percent of total grade— 60

**Section I of this examination contains 120 multiple-choice questions, followed by 15 multiple-choice questions regarding your preparation for this examination. Therefore, please be careful to fill in only the ovals that are preceded by numbers 1 through 135 on your answer sheet.**

#### General Instructions

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

INDICATE ALL YOUR ANSWERS TO QUESTIONS IN SECTION I ON THE SEPARATE ANSWER SHEET ENCLOSED. No credit will be given for anything written in this examination booklet, but you may use the book for notes or scratchwork. After you have decided which of the suggested answers is best, COMPLETELY fill in the corresponding oval on the answer sheet. Give only one answer to each question. If you change an answer, be sure that the previous mark is erased completely.

#### Example:

- Chicago is a  
(A) state  
(B) city  
(C) country  
(D) continent  
(E) village

#### Sample Answer

(A) ● (C) (D) (E)

Many candidates wonder whether or not to guess the answers to questions about which they are not certain. In this section of the examination, as a correction for haphazard guessing, one-fourth of the number of questions you answer incorrectly will be subtracted from the number of questions you answer correctly. It is improbable, therefore, that mere guessing will improve your score significantly; it may even lower your score, and it does take time. If, however, you are not sure of the correct answer but have some knowledge of the question and are able to eliminate one or more of the answer choices as wrong, your chance of getting the right answer is improved, and it may be to your advantage to answer such a question.

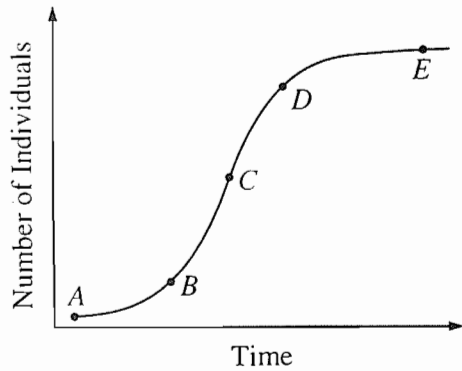
Use your time effectively, working as rapidly as you can without losing accuracy. Do not spend too much time on questions that are too difficult. Go on to other questions and come back to the difficult ones later if you have time. It is not expected that everyone will be able to answer all the multiple-choice questions.

BIOLOGY

SECTION I

Time—1 hour and 30 minutes

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



1. Which point on the curve in the diagram above best represents the carrying capacity of the environment for the population shown?

- (A) A
- (B) B
- (C) C
- (D) D
- (E) E

2. Assume that genes *A* and *B* are not linked. If the probability of allele *A* in a gamete is  $1/2$  and the probability of allele *B* in a gamete is  $1/2$ , then the probability that both *A* and *B* are in the same gamete is

- (A)  $1/2 \times 1/2$
- (B)  $1/2 + 1/2$
- (C)  $1/2 \div 1/2$
- (D)  $\sqrt{1/2}$
- (E)  $|1/2 - 1/2|$

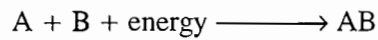
3. A couple has 5 children, all sons. If the woman gives birth to a sixth child, what is the probability that the sixth child will be a son?

- (A)  $\frac{5}{6}$
- (B)  $\frac{1}{2}$
- (C)  $\frac{1}{5}$
- (D)  $\frac{1}{6}$
- (E)  $\frac{1}{64}$

4. All of the following are true about Earth's ozone layer EXCEPT:

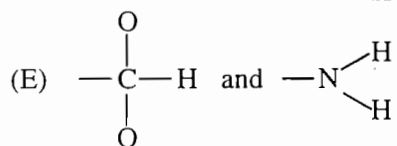
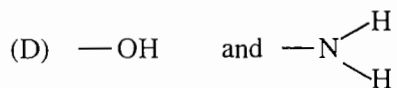
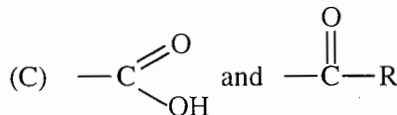
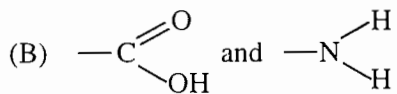
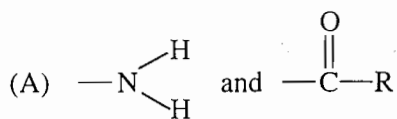
- (A) It shields Earth from most ultraviolet radiation.
- (B) It is composed of  $O_3$ .
- (C) Its thickness has remained constant over time.
- (D) CFC (chlorofluorocarbon) molecules can destroy ozone molecules.
- (E) It is predicted that a reduction of this layer will result in an increase in human skin cancer.

5. Which of the following organelles modifies and packages for secretion the materials produced by the ribosomes?
- (A) The chloroplast
  - (B) The Golgi apparatus
  - (C) The nucleus
  - (D) The nucleolus
  - (E) The mitochondrion
6. Which of the following types of behavior describes the way that mice find their way through mazes?
- (A) Habituation
  - (B) Imprinting
  - (C) Reasoning
  - (D) Instinct
  - (E) Trial and error
7. A student using a light microscope observes a cell and correctly decides that it is a plant cell because
- (A) ribosomes are visible
  - (B) an endoplasmic reticulum can be seen
  - (C) a cell membrane is present
  - (D) it has a large central vacuole
  - (E) centrioles are present
8. The condition in which there are barriers to successful interbreeding between individuals of different species in the same community is referred to as
- (A) latent variations
  - (B) sterility
  - (C) structural differences
  - (D) geographic isolation
  - (E) reproductive isolation
9. Which of the following best describes the parents in a testcross?
- (A) One individual has the dominant phenotype and the other has the recessive phenotype.
  - (B) Both individuals are heterozygous.
  - (C) Both individuals have the dominant phenotype.
  - (D) Both individuals have the recessive phenotype.
  - (E) Both individuals have an unknown phenotype.
10. Members of which of the following are the major primary producers in the marine ecosystem?
- (A) Yeasts
  - (B) Sponges
  - (C) Sporozoans
  - (D) Fishes
  - (E) Diatoms
11. In sheep, eye color is controlled by a single gene with two alleles. When a homozygous brown-eyed sheep is crossed with a homozygous green-eyed sheep, blue-eyed offspring are produced. If the blue-eyed sheep are mated with each other, what percent of their offspring will most likely have brown eyes?
- (A) 0%
  - (B) 25%
  - (C) 50%
  - (D) 75%
  - (E) 100%
12. Gas exchange in all living organisms requires
- (A) gills
  - (B) lungs
  - (C) tracheoles
  - (D) moist membranes
  - (E) blood
13. Which of the following best supports the statement that mitochondria are descendants of endosymbiotic bacteria-like cells?
- (A) Mitochondria and bacteria possess similar ribosomes and DNA.
  - (B) Mitochondria and bacteria possess similar nuclei.
  - (C) Glycolysis occurs in both mitochondria and bacteria.
  - (D) Both mitochondria and bacteria have microtubules.
  - (E) Neither mitochondria nor bacteria possess chloroplasts.



14. Which of the following best characterizes the reaction represented above?
- (A) Hydrolysis
  - (B) Catabolism
  - (C) Oxidation-reduction
  - (D) Exergonic reaction
  - (E) Endergonic reaction
15. Which of the following occurs during mitosis but not during meiosis I ?
- (A) The chromosomes are pulled to opposite poles of the spindle apparatus.
  - (B) The chromatids of each chromosome are separated.
  - (C) The nuclear envelope breaks down.
  - (D) Both synapsis and crossing-over take place.
  - (E) The diploid number of chromosomes is reduced to the haploid number.
16. Oxygen consumption can be used as a measure of metabolic rate because oxygen is
- (A) necessary for ATP synthesis by oxidative phosphorylation
  - (B) necessary to replenish glycogen levels
  - (C) necessary for fermentation to take place
  - (D) required by all living organisms
  - (E) required to break down the ethanol that is produced in muscles
17. Membranes are components of all of the following EXCEPT a
- (A) microtubule
  - (B) nucleus
  - (C) Golgi apparatus
  - (D) mitochondrion
  - (E) lysosome
18. In a mesophyll cell of a leaf, the synthesis of ATP occurs in which of the following?
- I. Ribosomes
  - II. Mitochondria
  - III. Chloroplasts
- (A) I only
  - (B) II only
  - (C) III only
  - (D) II and III only
  - (E) I, II, and III

19. Which of the following pairs of functional groups characterizes the structure of an amino acid?



20. Which of the following statements best expresses the concept of punctuated equilibrium?

- (A) Small variations gradually accumulate in evolving lineages over periods of millions of years.
- (B) Random mating ensures that the proportions of genotypes in a population remain unchanged from generation to generation.
- (C) Stability is achieved when selection favors the heterozygote, while both types of homozygotes are at a relative disadvantage.
- (D) Evolutionary changes consist of rapid bursts of speciation alternating with long periods in which species remain essentially unmodified.
- (E) Under competition for identical resources, one of the two competing species will be eliminated or excluded.

21. In animals, all of the following are associated with embryonic development EXCEPT

- (A) migration of cells to specific areas
- (B) formation of germ layers
- (C) activation of all the genes in each cell
- (D) inductive tissue interactions
- (E) cell division at a relatively rapid rate

22. Which of the following exists as RNA surrounded by a protein coat?

- (A) Retrovirus
- (B) Prion
- (C) Prokaryote
- (D) Spirochete
- (E) Streptococcus

23. Prokaryotic and eukaryotic cells generally have which of the following features in common?
- (A) A membrane-bound nucleus
  - (B) A cell wall made of cellulose
  - (C) Ribosomes
  - (D) Flagella or cilia that contain microtubules
  - (E) Linear chromosomes made of DNA and protein
24. Which of the following is primarily responsible for cell elongation, gravitropism, and apical dominance in plants?
- (A) Auxin
  - (B) Gibberellin
  - (C) Cytokinin
  - (D) Phytochrome
  - (E) Ethylene
25. A large stand of aspen trees may be a group of genetically identical individuals produced by vegetative reproduction. Such a collection of individuals is called a
- (A) family
  - (B) hybrid
  - (C) clone
  - (D) genus
  - (E) community
26. Which of the following groups contains prokaryotic organisms capable of surviving the greatest extremes in temperature or salt concentration?
- (A) Protista
  - (B) Archaeobacteria
  - (C) Plantae
  - (D) Fungi
  - (E) Viruses
27. Which of the following is LEAST likely to result in a release of epinephrine (adrenaline) from the adrenal glands?
- (A) Competing in an athletic event
  - (B) Going out on a first date
  - (C) Falling asleep during a lecture
  - (D) Swimming in a very cold pool
  - (E) Taking a test while unprepared

28. In peas the trait for tall plants is dominant ( $T$ ) and the trait for short plants is recessive ( $t$ ). The trait for yellow seed color is dominant ( $Y$ ) and the trait for green seed color is recessive ( $y$ ). A cross between two plants results in 296 tall yellow plants and 104 tall green plants. Which of the following are most likely to be the genotypes of the parents?
- (A)  $TTYy \times TTYy$
  - (B)  $Ttyy \times TTYy$
  - (C)  $TtYy \times TtYy$
  - (D)  $TtYy \times TTYy$
  - (E)  $TtYY \times Ttyy$
29. Which of the following is best observed by using a compound light microscope?
- (A) A eukaryotic cell
  - (B) A virus
  - (C) A DNA sequence
  - (D) The inner structure of a mitochondrion
  - (E) A nuclear pore
30. Plant stems bend toward a light source as a result of increased
- (A) chlorophyll synthesis on the side of the stem near the light source
  - (B) cell division on the side of the stem near the light source
  - (C) cell division on the side of the stem away from the light source
  - (D) cell elongation on the side of the stem near the light source
  - (E) cell elongation on the side of the stem away from the light source
31. All of the following are typical components of the plasma membrane of a eukaryotic cell EXCEPT
- (A) glycoproteins
  - (B) cytochromes
  - (C) cholesterol
  - (D) phospholipids
  - (E) integral proteins



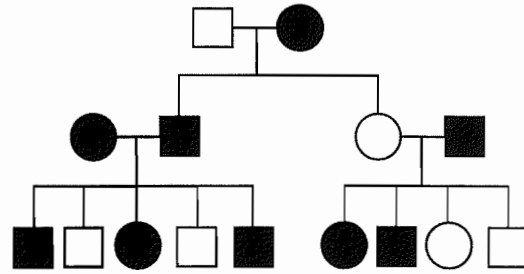
32. The rate of division of most vertebrate cells is LEAST likely to be influenced by which of the following?
- (A) Contact with other cells
  - (B) The availability of nutrients
  - (C) Compounds that inhibit protein synthesis
  - (D) The cell's photoperiod
  - (E) The temperature of the organism
33. The gametophyte is the dominant generation in which of the following plants?
- (A) Dicots
  - (B) Monocots
  - (C) Gymnosperms
  - (D) Ferns
  - (E) Mosses
34. Nuclear division in which the chromosome number is reduced from  $2n$  to  $n$  is part of the life cycle of all of the following organisms EXCEPT
- (A) molds
  - (B) ferns
  - (C) insects
  - (D) bacteria
  - (E) protozoans
35. The driving force for the movement of materials in the phloem of plants is
- (A) gravity
  - (B) a difference in osmotic potential between the source and the sink
  - (C) root pressure
  - (D) transpiration of water through the stomates
  - (E) adhesion of water to vessel elements
36. In plants, the initiation of flowering in response to photoperiod is triggered by changes in
- (A) ethylene
  - (B) auxin
  - (C) gibberellic acid
  - (D) phytochrome
  - (E) cytokinin
37. Carbon dioxide is transported in human blood primarily in which of the following ways?
- (A) As oxyhemoglobin
  - (B) As bicarbonate ions
  - (C) Attached to plasma proteins
  - (D) Attached to the amino groups of hemoglobin
  - (E) Attached to the heme groups of hemoglobin
38. A tobacco plant can be made to express a gene from fireflies, resulting in the emission of light. Which of the following is the basis for this phenomenon?
- (A) Chloroplasts can be made to produce light if firefly proteins are injected into plant cells.
  - (B) Fireflies and tobacco plants share a recent common ancestor.
  - (C) Fireflies and tobacco plants are infected by the same kinds of bacteria.
  - (D) Transcription and translation are fundamentally similar in both fireflies and tobacco plants.
  - (E) Most enzymes in fireflies have the same amino acid sequence as the enzymes in tobacco plants.

39. All of the following were likely present on the primitive Earth during the evolution of self-replicating molecules EXCEPT
- (A) amino acids and nucleotides
  - (B) nitrogen
  - (C) simple carbohydrates
  - (D) freestanding liquid water
  - (E) an O<sub>2</sub>-rich atmosphere
40. Which of the following characterizes glomerular filtrate, the fluid that passes from the blood in the glomerulus into the tubule of the nephron?
- (A) It is clear in appearance and contains no glucose.
  - (B) It is a concentrated solution of waste products.
  - (C) It is identical to blood plasma.
  - (D) It is blood plasma that lacks most proteins.
  - (E) It is whole blood.
41. During respiration, most ATP is formed as a direct result of the net movement of
- (A) potassium against a concentration gradient
  - (B) protons down a concentration gradient
  - (C) electrons against a concentration gradient
  - (D) electrons through a channel
  - (E) sodium ions into the cell
42. Which of the following groups is best characterized as being eukaryotic and heterotrophic and having chitinous cell walls?
- (A) Plantae
  - (B) Animalia
  - (C) Fungi
  - (D) Virus
  - (E) Monera
43. In humans, red-green color blindness is a sex-linked recessive trait. If a man and a woman produce a color-blind son, which of the following must be true?
- (A) The father is color-blind.
  - (B) Both parents carry the allele for color blindness.
  - (C) Neither parent carries the allele for color blindness.
  - (D) The father carries the allele for color blindness.
  - (E) The mother carries the allele for color blindness.

44. In a small group of people living in a remote area, there is a high incidence of “blue skin”, a condition that results from a variation in the structure of hemoglobin. All of the “blue-skinned” residents can trace their ancestry to one couple, who were among the original settlers of this region. The unusually high frequency of “blue skin” in the area is an example of
- (A) mutation
  - (B) genetic drift
  - (C) natural selection
  - (D) sexual selection
  - (E) heterozygote advantage
45. Which of the following processes is carried out more efficiently by a  $C_4$  plant than by a  $C_3$  plant?
- (A) Light absorption
  - (B) Chemiosmotic coupling
  - (C) Photolysis
  - (D) Fixation of  $CO_2$
  - (E) Transport of sugars
46. A number of different phylogenies (evolutionary trees) have been proposed by scientists. These phylogenies are useful because they can be used to
- (A) determine when two similar populations of a species evolved into two separate species
  - (B) evaluate which groups of organisms may be most closely related
  - (C) demonstrate that all photosynthetic organisms are members of the Kingdom Plantae
  - (D) demonstrate that natural selection is the prevailing force in evolution
  - (E) demonstrate which taxa (groups of organisms) contain the most highly evolved species
47. Which of the following characteristics is common to all vascular plants that exhibit an alternation of generations in their life cycle?
- (A) Large, independent gametophytes
  - (B) Multicellular sporophytes
  - (C) Fertilization in water
  - (D) Diploid spores
  - (E) Seed production

48. The rate of flow of water through the xylem is regulated by
- (A) passive transport by the pith
  - (B) the force of transpirational pull
  - (C) the number of companion cells in the phloem
  - (D) active transport by the sieve-tube members
  - (E) active transport by tracheid and vessel cells
49. Which of the following pathways for the transformation of cellular energy most likely evolved first?
- (A) Cyclic photophosphorylation
  - (B) Citric acid (Krebs) cycle
  - (C) Calvin cycle
  - (D)  $C_4$  photosynthesis
  - (E) Glycolysis
50. Gibberellic acid stimulates the cells of germinating grass seeds to produce mRNA molecules that code for hydrolytic enzymes. In this case the role of gibberellic acid can best be described as that of
- (A) a regulator of gene activity
  - (B) a stimulator of hydrolase secretion
  - (C) a stimulator of DNA replication
  - (D) an allosteric activator of hydrolase
  - (E) an activator of translation
51. Which of the following is the most likely explanation for a high rate of crossing-over between two genes?
- (A) The two genes are far apart on the same chromosome.
  - (B) The two genes are both located near the centromere.
  - (C) The two genes are sex-linked.
  - (D) The two genes code for the same protein.
  - (E) The two genes are on different chromosomes.
52. On a sunny day, the closing of stomata in plant leaves results in
- (A) a decrease in  $CO_2$  intake
  - (B) a shift from  $C_3$  photosynthesis to  $C_4$  photosynthesis
  - (C) an increase in transpiration
  - (D) an increase in the concentration of  $CO_2$  in mesophyll cells
  - (E) an increase in the rate of production of starch
53. Which of the following principles is NOT part of Darwin's theory of evolution by natural selection?
- (A) Evolution is a gradual process that occurs over long periods of time.
  - (B) Variation occurs among individuals in a population.
  - (C) Mutations are the ultimate source of genetic variation.
  - (D) More individuals are born than will survive.
  - (E) Individuals that possess the most favorable variations have the best chance of reproducing.

54. In certain Native American groups, albinism due to a homozygous recessive condition in the biochemical pathway for melanin is sometimes seen. If the frequency of the allele for this condition is 0.06, which of the following is closest to the frequency of the dominant allele in this population? (Assume that the population is in Hardy-Weinberg equilibrium.)



- (A) 0.04
  - (B) 0.06
  - (C) 0.16
  - (D) 0.36
  - (E) 0.94
55. A biologist isolates numerous tiny, green-pigmented cells from a sample of lake water. The cells are covered with a mucilaginous sheath. They contain relatively large amounts of chlorophyll *a* and phycobilin pigments and lack a compact, organized nucleus. Electron microscopy will reveal that these cells also contain which of the following pairs of subcellular structures?
- (A) Ribosomes and chloroplasts
  - (B) Ribosomes and mitochondria
  - (C) Golgi bodies and a cell wall
  - (D) Thylakoids and a cell wall
  - (E) Chloroplasts and mitochondria

56. In the pedigree above, squares represent males and circles represent females. Individuals who express a particular trait are represented by shaded figures. Which of the following patterns of inheritance best explains the transmission of the trait?

- (A) Sex-linked dominant
  - (B) Sex-linked recessive
  - (C) Autosomal recessive
  - (D) Autosomal dominant
  - (E) Incompletely dominant
57. Which of the following is an example of active transport across a membrane?
- (A) The movement of water from a nephron into the collecting duct of the kidney
  - (B) The movement of glucose by facilitated diffusion into a liver cell
  - (C) The movement of water from the inside of a cell into a surrounding hypertonic medium
  - (D) The movement of  $\text{Na}^+$  into a neuron as a nerve impulse is generated
  - (E) The movement of  $\text{H}^+$  into a thylakoid disc during photosynthesis

58. Which of the following is the most direct result of the presence of acid chyme in the small intestine?
- (A) The liver produces insulin.
  - (B) The pancreas produces hydrolytic enzymes.
  - (C) The stomach produces pepsin.
  - (D) The intestinal lining produces the hormone secretin.
  - (E) The gall bladder releases bile.
59. Many parasitic flatworms have an intermediate host. This indicates that the
- (A) flatworms cannot infect humans
  - (B) larval flatworms infect one species, whereas adults infect another species
  - (C) larval flatworms infect only juveniles of a species
  - (D) flatworm adults are microscopic
  - (E) flatworm larvae are parasitic on their parents
60. Red algae can grow at greater ocean depths than most other algae can because red algae are
- (A) specialized for absorbing red wavelengths of light for photosynthesis.
  - (B) specialized for absorbing ultraviolet wavelengths of light for photosynthesis.
  - (C) specialized for absorbing blue wavelengths of light for photosynthesis.
  - (D) unable to use chlorophyll for photosynthesis.
  - (E) adapted for chemosynthesis, rather than photosynthesis.

61. Which of the following cellular processes is coupled with the hydrolysis of ATP?

- (A) Facilitated diffusion
- (B) Active transport
- (C) Chemiosmosis
- (D) Osmosis
- (E)  $\text{Na}^+$  influx into a nerve cell

Item 62 was not scored.

63. Which of the following cells would most likely have the greatest concentration of densely packed rough endoplasmic reticulum?

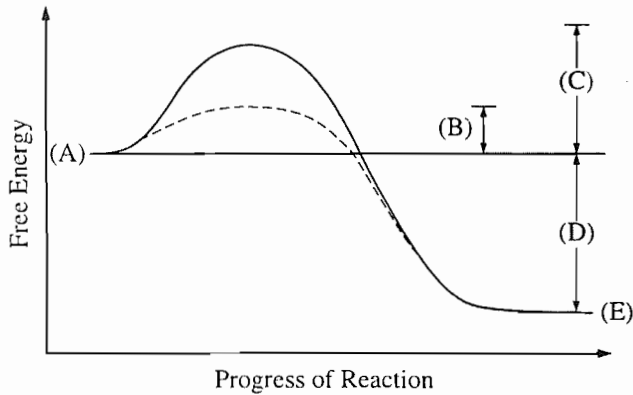
- (A) An amoeba engulfing small ciliates
- (B) A bioluminescent bacterial cell
- (C) A pancreatic cell engaged in the production of digestive enzymes
- (D) A functional phloem cell at maturity
- (E) An epithelial cell whose DNA is replicating before mitosis

64. In which of the following pairs are the organisms most closely related taxonomically?

- (A) Mushroom..oak tree
- (B) Spider..crayfish
- (C) Bacterium..paramecium
- (D) Sea star (starfish)..clam
- (E) Rosebush..diatom

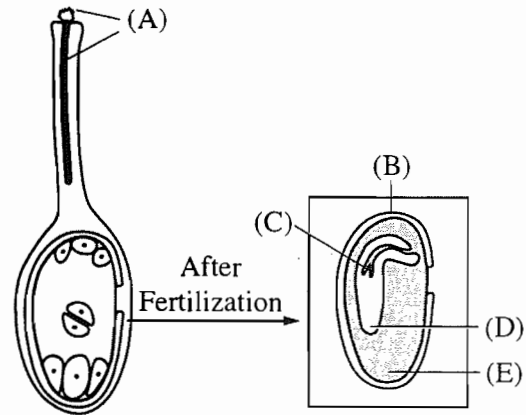
**Directions:** Each group of questions below consists of five lettered headings followed by a list of numbered phrases or sentences. For each numbered phrase or sentence select the one heading that is most closely related to it and fill in the corresponding oval on the answer sheet. Each heading may be used once, more than once, or not at all in each group.

Questions 65-68 refer to the following graph. The solid curve and the dashed curve represent alternate pathways for the same reaction. One pathway is enzyme catalyzed.



- 65. Represents the activation energy of the enzyme-catalyzed reaction
- 66. Represents the net energy change of the reaction
- 67. Represents the energy state of the products of the enzyme-catalyzed pathway
- 68. Represents the energy state of the products of the pathway that is not enzyme-catalyzed

Questions 69-73 refer to the following diagram of angiosperm reproduction.



- 69. Root meristem
- 70. Male gametophyte
- 71. Triploid nutritive tissue (endosperm)
- 72. Seed coat
- 73. Apical meristem of the shoot



Questions 74-77

- (A) Testis
- (B) Lining of small intestine
- (C) Anterior pituitary
- (D) Thyroid
- (E) Pancreas

74. Releases hormones that control blood sugar levels by stimulating glycogen formation or breakdown
75. Secretes steroid hormones that affect secondary sex characteristics
76. Releases hormones that increase the rate of cellular respiration throughout the body
77. Secretes the hormones FSH and LH, which control ovulation

Questions 78-81

- (A) Deciduous forest
- (B) Tropical rain forest
- (C) Desert
- (D) Tundra
- (E) Taiga

78. Long, cold, moist winters and short summers are typical of this biome dominated by gymnosperms.
79. A prolonged, relatively mild period with ample precipitation alternates with a cold period when plants become dormant.
80. This biome has the greatest diversity of species.
81. This biome is dominated by dwarf shrubs, grasses, and sedges that can tolerate long dark winters.

Questions 82-86

- (A) Glycolysis
  - (B) Krebs cycle (citric acid cycle)
  - (C) Calvin cycle (light-independent reactions of photosynthesis)
  - (D) Light-dependent reactions of photosynthesis
  - (E) Chemiosmosis
82. Process in which  $O_2$  is released as a by-product of oxidation-reduction reactions
83. Process in which  $CO_2$  is released as a by-product of oxidation-reduction reactions
84. Process in which carbon from  $CO_2$  is incorporated into organic molecules
85. Process found in both photosynthesis and cellular respiration
86. Process in which sugar is oxidized to pyruvic acid

Questions 87-91

- (A) Annelida
  - (B) Mollusca
  - (C) Arthropoda
  - (D) Echinodermata
  - (E) Chordata
87. Bilaterally symmetrical; deuterostome; dorsal hollow nerve cord
88. Coelomate; exoskeleton; jointed appendages
89. Pharyngeal slits; endoskeleton derived from mesoderm; ventral heart
90. Internal calcareous skeleton; deuterostome; water-vascular system
91. Closed circulatory system; protostome; many body segments

Questions 92-95

- (A) Transcription
  - (B) Translation
  - (C) Transformation
  - (D) Replication
  - (E) Reverse transcription
92. Process in which a protein is assembled at a ribosome
93. Process in which naked DNA is taken up by a bacterial or yeast cell
94. Process that results in the production of cDNA from an RNA molecule
95. Process in which RNA is produced by using a DNA template

Directions: Each group of questions below concerns an experimental or laboratory situation or data. In each case, first study the description of the situation or data. Then choose the one best answer to each question following it and fill in the corresponding oval on the answer sheet.

Questions 96-99

A scientist is using an ampicillin-sensitive strain of bacteria that cannot use lactose because it has a nonfunctional gene in the *lac* operon. She has two plasmids. One contains a functional copy of the affected gene of the *lac* operon, and the other contains the gene for ampicillin resistance. Using restriction enzymes and DNA ligase, she forms a recombinant plasmid containing both genes. She then adds a high concentration of the plasmid to a tube of the bacteria in a medium for bacterial growth that contains glucose as the only energy source. This tube (+) and a control tube (-) with similar bacteria but no plasmid are both incubated under the appropriate conditions for growth and plasmid uptake. The scientist then spreads a sample of each bacterial culture (+ and -) on each of the three types of plates indicated below.

	Glucose Medium	Glucose Medium with Ampicillin	Glucose Medium with Ampicillin and Lactose
Bacterial strain with added plasmid (+)	#1	#2	#3
Bacterial strain with no plasmid (-)	#4	#5	#6

96. If no new mutations occur, it would be most reasonable to expect bacterial growth on which of the following plates?
- (A) 1 and 2 only
  - (B) 3 and 4 only
  - (C) 5 and 6 only
  - (D) 4, 5, and 6 only
  - (E) 1, 2, 3, and 4 only
97. The scientist used restriction enzymes for what purpose in the experiment?
- (A) To make the plasmid small enough to transform cells
  - (B) To make cuts in the plasmid DNA
  - (C) To make the plasmid enter the cells
  - (D) To enable the fragments of DNA to form covalent bonds
  - (E) To enable the plasmid to recognize the bacterial cells

98. If the scientist had forgotten to use DNA ligase during the preparation of the recombinant plasmid, bacterial growth would most likely have occurred on which of the following?
- (A) 1 and 2 only
  - (B) 1 and 4 only
  - (C) 4 and 5 only
  - (D) 1, 2, and 3 only
  - (E) 4, 5, and 6 only

	Lactose Medium	Lactose Medium with Ampicillin
Bacterial strain with added plasmid (+)	#7	#8
Bacterial strain with no plasmid (-)	#9	#10

99. If the scientist used the cultures to perform another experiment as shown above, using medium that contained lactose as the only energy source, growth would most likely occur on which of the following plates?
- (A) 10 only
  - (B) 7 and 8 only
  - (C) 7 and 9 only
  - (D) 8 and 10 only
  - (E) 9 and 10 only

Questions 100-101

In a study of the development of frogs, groups of cells in the germ layers of several embryos in the early gastrula stage were stained with five different dyes that do not harm living tissue. After organogenesis (organ formation), the location of the dyes was noted, as shown in the table below.

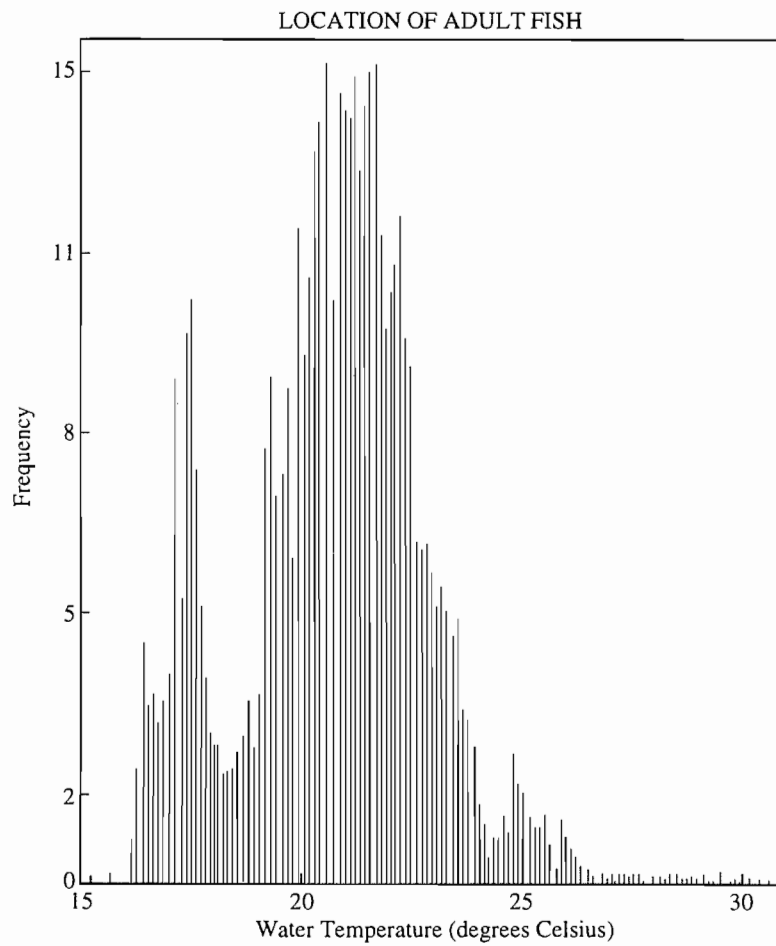
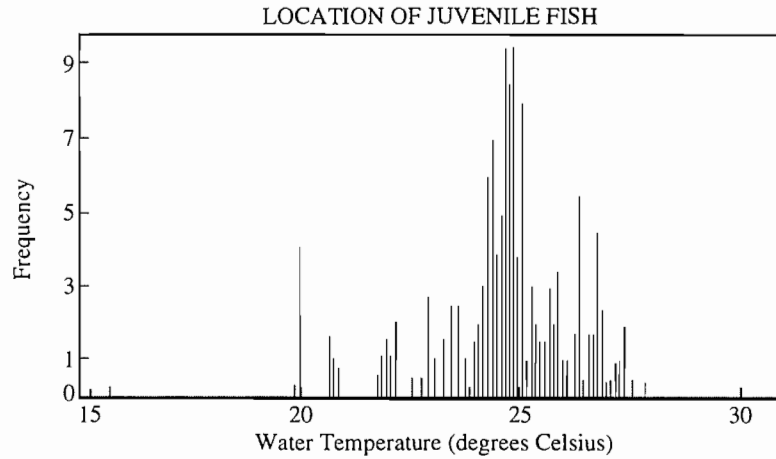
<u>Tissue</u>	<u>Stain</u>
Brain	Red
Notochord	Yellow
Liver	Green
Lens of the eye	Blue
Lining of the digestive tract	Purple

100. Ectoderm would eventually give rise to tissues containing which of the following colors?
- (A) Red and blue
  - (B) Yellow and purple
  - (C) Green and red
  - (D) Green and yellow
  - (E) Purple and green
101. Tissues stained with the purple dye were probably derived from
- (A) the ectoderm only
  - (B) the mesoderm only
  - (C) the endoderm only
  - (D) both the ectoderm and the mesoderm
  - (E) both the endoderm and the mesoderm

Questions 102-103 refer to the birth of a child with blood type A to a mother with blood type B

102. The father must have which of the following blood types?
- (A) AB only
  - (B) Either AB or B
  - (C) Either AB or O
  - (D) Either AB or A
  - (E) AB or A or O
103. If the father has blood type AB, which of the following statements is correct about the mother?
- (A) She contributes an  $I^B$  allele, which is recessive to the father's  $I^A$  allele.
  - (B) She contributes an  $i$  allele, which is recessive to the father's  $I^A$  allele.
  - (C) She contributes an  $I^B$  allele, which is codominant to the father's  $I^A$  allele.
  - (D) She contributes an  $i$  allele, which is codominant to the father's  $I^B$  allele.
  - (E) She is homozygous for the  $I^B$  allele.

Questions 104-106 refer to the following graphs.



The data in the graphs above represent the frequency with which juveniles and adults of a species of fish are found at different water temperatures. Observations were made of several juveniles in a laboratory tank and of three tagged adults in a reservoir during the summer.

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104. The most accurate conclusion to be drawn solely from the graphs is that
- (A) adult fish of this species are found more frequently in water at 22°C than are juveniles
  - (B) fish of this species are found most frequently in water at 20°C
  - (C) the optimum water temperature for fish of this species is 25°C
  - (D) the oxygen content of cool water is higher than that of warm water
  - (E) the oxygen content of warm water is higher than that of cool water
105. Which of the following statements about the results is true?
- (A) They are invalid, because the data show too much variation.
  - (B) They are invalid, because part of the experiment was not done in the laboratory.
  - (C) They are inconclusive, because too few fish were used.
  - (D) They are inaccurate, because tanks with temperature gradients were used.
  - (E) They are improperly graphed, because the dependent variable is on the horizontal (x) axis.
106. The purpose of the study is most likely to
- (A) determine the water temperature at which fish of this species spawn
  - (B) determine the role of fish of this species in the ecosystem
  - (C) show that juveniles occur in smaller numbers than do adults of this species
  - (D) demonstrate the effects of adult fish of this species on water temperature
  - (E) study the relationship between water temperature and habitat selection in fish of this species

Questions 107-110 refer to the information and table below.

The following information was gathered from a study to determine the relationship between structure and function in the digestive tracts of several animals.

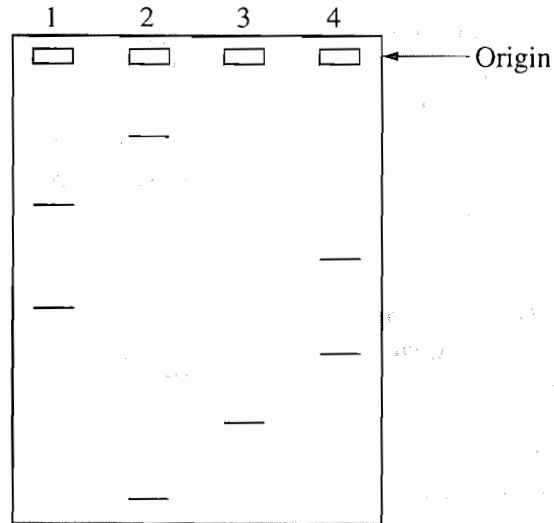
	Mode of Nutrition	Body Length	Intestinal Length	Intestinal Features	Components of Digestive Tract Present	Percentage of Ingested Nutrients Remaining in Feces
1	Carnivore	0.01 m	0.01 m	Extensive branching	Mouth, pharynx, intestine	30% of ingested nutrients remaining
2	Carnivore	0.10 m	0.13m	Villi and folds in wall	Mouth, esophagus, stomach, intestine, accessory organs, anus	15% of ingested nutrients remaining
3	Omnivore	1.83 m	5.62 m	Villi and folds in wall	Mouth, esophagus, stomach, intestine, accessory organs, anus	11% of ingested nutrients remaining
4	Herbivore	2.59 m	7.92 m	Villi and folds in wall	Mouth, esophagus, stomach, intestine, accessory organs, anus	4% of ingested nutrients remaining
5	Herbivore	1.98 m	21.33 m	Villi and folds in wall	Mouth, esophagus, stomach, intestine, accessory organs, anus	10% of ingested nutrients remaining

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107. Which of the following can be correctly concluded about the relationship between intestinal length and body size for the organisms in the table?
- (A) Carnivores have greater intestinal length relative to body size than do herbivores.
  - (B) Herbivores have greater intestinal length relative to body size than do carnivores.
  - (C) Omnivores have greater intestinal length relative to body size than do either carnivores or herbivores.
  - (D) The smaller the intestinal length relative to body size, the more nutrients are absorbed.
  - (E) No relationship exists between intestinal length and mode of nutrition.
108. Which of the animals is most likely to have, living in specialized areas of its digestive tract, abundant symbiotic bacteria that break down foods that the animal normally could not digest on its own?
- (A) 1
  - (B) 2
  - (C) 3
  - (D) 4
  - (E) 5
109. Which animal has a gastrovascular cavity?
- (A) 1
  - (B) 2
  - (C) 3
  - (D) 4
  - (E) 5
110. Which animal is most efficient in absorbing the food it consumes?
- (A) 1
  - (B) 2
  - (C) 3
  - (D) 4
  - (E) 5

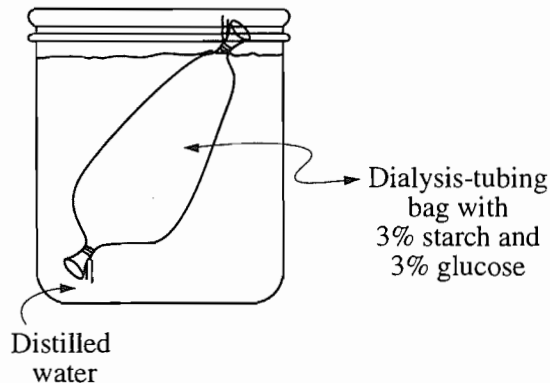
Questions 111-113 refer to an experiment that was performed to separate DNA fragments from four samples radioactively labeled with  $^{32}\text{P}$ . The fragments were separated by gel electrophoresis. The visualized bands are illustrated in the figure below.



Gel Electrophoresis of DNA Fragments

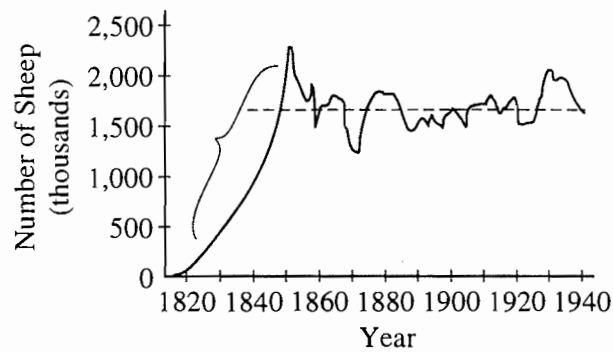
111. The electrophoretic separation of the pieces of DNA in each of the four samples was achieved because of differential migration of the DNA fragments in an electric field. This differential migration was caused by the
- (A) relative amounts of radioactivity in the DNA
  - (B) number of cleavage points per fragment
  - (C) size of each fragment
  - (D) overall positive charge of each fragment
  - (E) solubility of each fragment
112. The DNA was labeled with  $^{32}\text{P}$  in order to
- (A) stimulate DNA replication
  - (B) inhibit the uptake of unlabeled ATP
  - (C) show which fragments included the 5' end and which fragments included the 3' end
  - (D) visualize the fragments
  - (E) speed up the rate of separation by electrophoresis
113. Which of the following is an additional use of the gel electrophoresis technique?
- (A) To express a gene
  - (B) To separate proteins in a mixture
  - (C) To ligate DNA fragments
  - (D) To transform *E. coli*
  - (E) To amplify genes

Questions 114-116 refer to an experiment in which a dialysis-tubing bag is filled with a mixture of 3% starch and 3% glucose and placed in a beaker of distilled water, as shown below. After 3 hours, glucose can be detected in the water outside the dialysis-tubing bag, but starch cannot.



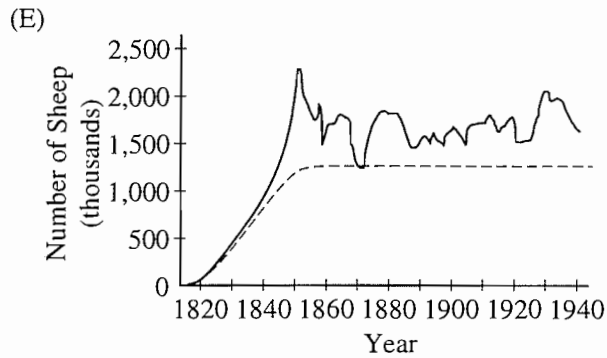
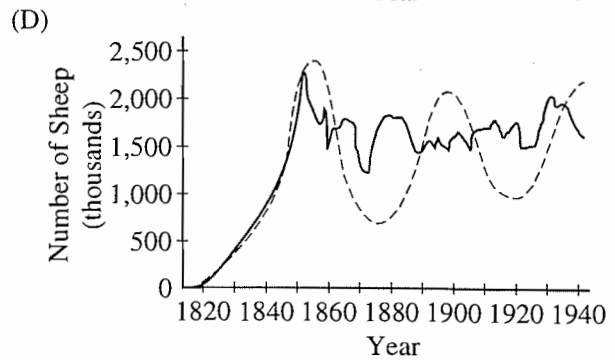
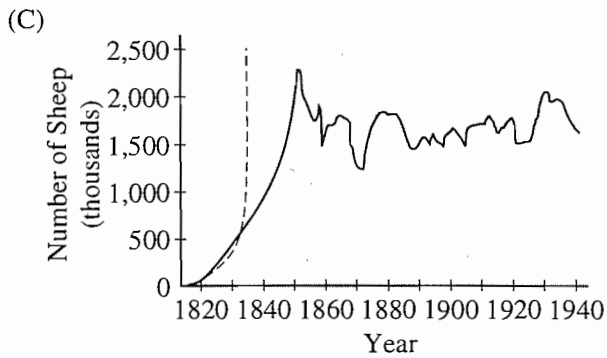
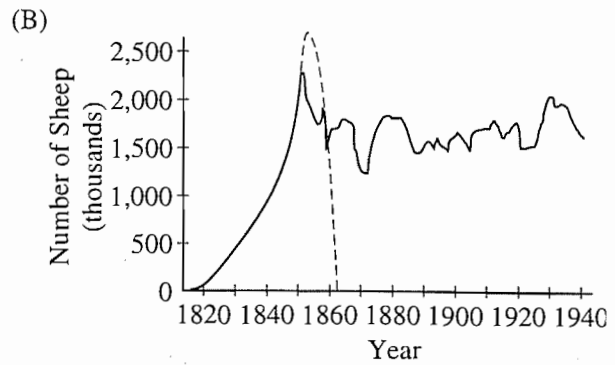
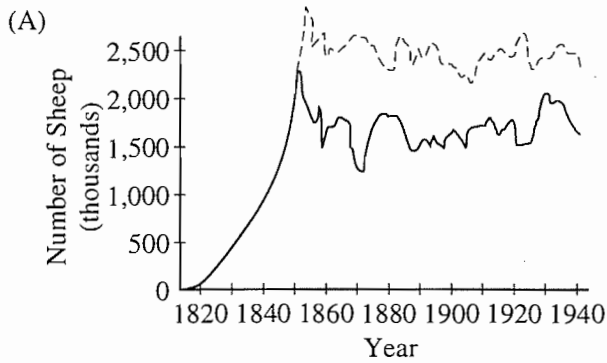
114. From the initial conditions and results described, which of the following is a logical conclusion?
- (A) The initial concentration of glucose in the bag is higher than the initial concentration of starch in the bag.
  - (B) The pores of the bag are larger than the glucose molecules but smaller than the starch molecules.
  - (C) The bag is not selectively permeable.
  - (D) A net movement of water into the beaker has occurred.
  - (E) The molarity of the solution in the bag and the molarity of the solution in the surrounding beaker are the same.
115. Which of the following best describes the condition expected after 24 hours?
- (A) The bag will contain more water than it did in the original condition.
  - (B) The contents of the bag will have the same osmotic concentration as the surrounding solution.
  - (C) Water potential in the bag will be greater than water potential in the surrounding solution.
  - (D) Starch molecules will continue to pass through the bag.
  - (E) A glucose test on the solution in the bag will be negative.
116. If, instead of the bag, a potato slice were placed in the beaker of distilled water, which of the following would be true of the potato slice?
- (A) It would gain mass.
  - (B) It would neither gain nor lose mass.
  - (C) It would absorb solutes from the surrounding liquid.
  - (D) It would lose water until water potential inside the cells is equal to zero.
  - (E) The cells of the potato would increase their metabolic activity.

Questions 117-120 The graph below shows changes in a population of wild sheep that were introduced to the island of Tasmania in the early 1800's.



117. The type of population growth represented by that portion of the graph line enclosed in the bracket is most accurately termed
- (A) stable
  - (B) exponential
  - (C) density-dependent
  - (D) arithmetic
  - (E) decelerating
118. The graph indicates that the sheep population most likely is
- (A) growing in excess of its carrying capacity, since fluctuations in population size occurred after 1850
  - (B) headed for extinction because of the population explosion about 1930
  - (C) regulated by density-independent factors, because there appears to be about a 10-year cycle of sharp declines in size
  - (D) shifting from a *K*-selected strategy to an *r*-selected strategy
  - (E) stable after 1850 under the effects of density-dependent regulating factors
119. The dashed line on the graph represents the
- (A) maximum population size
  - (B) average birth rate
  - (C) biotic potential of the population
  - (D) carrying capacity of the environment
  - (E) point of maximum effect for density-independent factors

120. In the graphs below, the solid line represents the original population. The dotted line on which graph best represents the sheep population that would have resulted from a sustained increase in the primary productivity of the environment?



END OF SECTION I

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The College Board  
Advanced Placement Examination  
BIOLOGY  
SECTION II  
Time—1 hour and 30 minutes  
Number of questions—4  
Percent of total grade—40

Suggested writing time per question—approximately 22 minutes

Because each question will be weighted equally, you are advised to divide your time equally among them without spending too much time on any one question. You are expected to answer all four questions in this section. Suggested times will not be announced; you may proceed freely from one question to the next.

Each answer should be organized, well balanced, and as comprehensive as time permits. Answers must be in organized, well-written prose form; outline form is NOT acceptable. Do not spend time restating the questions. If a specific number of examples are called for, no credit will be given for additional examples. For instance, if a question calls for two examples, you will receive credit only for the first two examples you provide. Diagrams may be used to supplement discussion, but in no case will a diagram alone suffice.

You are to write your answers in this book only, preferably in black or dark blue ink. Be sure to write CLEARLY and LEGIBLY. If you make an error, you may save time by crossing it out rather than trying to erase it.

The questions for Section II are printed in the green insert. Use the green insert to organize your answers and for scratchwork, but write your answers in the pink booklet. Number each answer as the question is numbered in the examination. Do not skip lines. Begin each answer on a new page.



## BIOLOGY

## SECTION II

Time—1 hour and 30 minutes

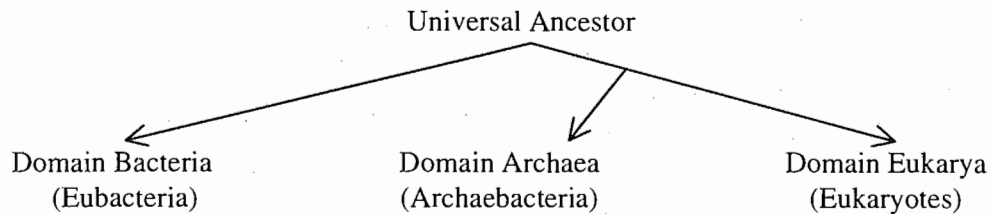
Answer all questions. Number your answer as the question is numbered below.

Answers must be in essay form. Outline form is NOT acceptable. Labeled diagrams may be used to supplement discussion, but in no case will a diagram alone suffice. It is important that you read each question completely before you begin to write.

1. The rate of photosynthesis may vary with changes that occur in environmental temperature, wavelength of light, and light intensity. Using a photosynthetic organism of your choice, choose only ONE of the three variables (temperature, wavelength of light, or light intensity) and for this variable
  - **design** a scientific experiment to determine the effect of the variable on the rate of photosynthesis for the organism;
  - **explain** how you would measure the rate of photosynthesis in your experiment;
  - **describe** the results you would expect. **Explain** why you would expect these results.
2. Communication occurs among the cells in a multicellular organism. Choose THREE of the following examples of cell-to-cell communication, and for each example, **describe** the communication that occurs and the types of responses that result from this communication.
  - Communication between two plant cells
  - Communication between two immune-system cells
  - Communication **either** between a neuron and another neuron, **or** between a neuron and a muscle cell
  - Communication between a specific endocrine-gland cell and its target cell

**GO ON TO THE NEXT PAGE**

3. Scientists recently have proposed a reorganization of the phylogenetic system of classification to include the domain, a new taxonomic category higher (more inclusive) than the Kingdom category, as shown in the following diagram.



- **Describe** how this classification scheme presents different conclusions about the relationships among living organisms than those presented by the previous five-kingdom system of classification.
  - **Describe** three kinds of evidence that were used to develop the taxonomic scheme above, and **explain** how this evidence was used. The evidence may be structural, physiological, molecular, and/or genetic.
  - **Describe** four of the characteristics of the universal ancestor.
4. Scientists seeking to determine which molecule is responsible for the transmission of characteristics from one generation to the next knew that the molecule must (1) copy itself precisely, (2) be stable but able to be changed, and (3) be complex enough to determine the organism's phenotype.
- **Explain** how DNA meets each of the three criteria stated above.
  - Select **one** of the criteria stated above and **describe** experimental evidence used to determine that DNA is the hereditary material.

END OF EXAMINATION

## Chapter III Answers to the 1999 AP Biology Examination

The format of the 1999 AP Biology Examination was similar to that of the 1998 Exam, with 120 multiple-choice questions (119 were scored) and four free-response (FR) questions. One multiple-choice question was not scored for statistical reasons.<sup>1</sup>

This chapter includes the answer key to the multiple-choice questions and the guidelines that the faculty consultants used to score the 1999 essays. It also contains sample student responses representing the high and middle ranges of the scoring scales. In reading these

responses, it should be remembered that they were written under examination conditions.

- Section I: Multiple Choice
  - Section I Answer Key and Percent Answering Correctly
- Section II: Free Response
  - Scoring Guidelines, Sample Student Responses, and Commentary

<sup>1</sup>Multiple-choice question number 62 was not scored.

## Section I: Multiple Choice

Listed below are the correct answers to the multiple-choice questions and the percentage of AP candidates who answered each question correctly.

### Section I Answer Key and Percent Answering Correctly

Item No.	Correct Answer	Percent Correct by Grade						Total
		5	4	3	2	1		
1	E	95	87	82	71	52	80	
2	A	97	93	87	79	61	86	
3	B	93	88	80	71	49	78	
4	C	98	96	94	91	81	94	
5	B	99	98	93	84	58	89	
6	E	88	82	77	72	57	77	
7	D	99	96	91	80	56	86	
8	E	83	70	63	58	50	66	
9	A	68	50	40	37	41	48	
10	E	70	56	46	32	17	48	
11	B	89	82	74	66	54	74	
12	D	89	75	62	45	21	61	
13	A	88	76	64	51	32	64	
14	E	89	74	60	41	25	61	
15	B	78	58	36	21	13	44	
16	A	91	82	69	52	34	68	
17	A	96	87	72	56	38	73	
18	D	59	44	39	35	30	42	
19	B	61	44	37	34	30	42	
20	D	87	71	55	42	25	57	
21	C	86	71	54	34	17	56	
22	A	92	82	69	54	29	69	
23	C	86	71	58	44	30	60	
24	A	79	64	56	44	25	57	
25	C	63	46	38	30	23	41	
26	B	87	74	60	46	32	62	
27	C	98	98	97	94	83	95	
28	D	71	60	50	43	30	51	
29	A	93	84	77	66	48	75	
30	E	77	66	56	40	18	54	
31	B	88	75	63	46	28	62	
32	D	69	56	42	29	23	46	
33	E	74	51	31	16	11	37	
34	D	79	60	43	31	17	48	
35	B	65	43	30	24	13	36	
36	D	48	32	22	15	12	27	
37	B	72	52	34	24	18	43	
38	D	58	38	29	23	20	33	
39	E	94	86	74	57	31	71	
40	D	40	18	13	14	16	20	
41	B	64	36	23	16	14	33	
42	C	82	62	45	30	20	51	
43	E	86	70	53	38	26	55	
44	B	76	60	49	43	44	56	
45	D	85	70	54	43	26	59	
46	B	82	66	53	36	22	53	
47	B	50	25	15	14	18	24	
48	B	91	74	55	37	23	58	
49	E	67	53	46	37	24	47	
50	A	44	22	12	10	8	20	
51	A	59	41	32	19	10	33	
52	A	90	79	67	53	36	67	
53	C	72	61	55	47	31	54	
54	E	88	75	63	50	26	63	
55	D	29	23	22	18	11	22	
56	D	62	47	37	29	19	40	
57	E	45	25	16	12	9	22	
58	D	38	26	25	25	23	27	
59	B	79	64	53	40	28	54	
60	C	41	25	23	17	12	23	

Item No. *	Correct Answer	Percent Correct by Grade						Total
		5	4	3	2	1		
61	B	67	48	41	36	34	46	
63	C	86	67	46	36	28	53	
64	B	67	49	35	25	15	40	
65	B	80	60	42	26	19	47	
66	D	87	69	52	35	20	55	
67	E	86	65	46	31	18	51	
68	E	82	56	37	24	18	45	
69	D	69	50	34	22	14	39	
70	A	92	79	61	41	22	62	
71	E	95	88	79	69	55	79	
72	B	100	99	98	96	87	97	
73	C	74	56	42	32	26	48	
74	E	86	78	71	65	48	71	
75	A	83	73	65	61	53	69	
76	D	71	64	57	48	37	57	
77	C	92	82	75	65	43	73	
78	E	77	61	51	42	28	53	
79	A	84	75	67	58	42	67	
80	B	99	98	96	92	82	95	
81	D	85	74	69	58	43	67	
82	D	75	57	47	38	23	49	
83	B	87	65	47	31	21	53	
84	C	86	60	36	23	16	46	
85	E	90	72	52	38	22	57	
86	A	94	82	71	60	43	72	
87	E	77	57	47	37	26	51	
88	C	94	83	73	61	41	72	
89	E	41	26	22	16	17	24	
90	D	62	43	32	23	16	38	
91	A	81	64	55	40	25	55	
92	B	93	74	53	33	21	57	
93	C	95	79	57	38	24	61	
94	E	94	81	58	43	27	62	
95	A	91	75	57	41	25	60	
96	E	91	71	43	22	10	49	
97	B	90	75	54	34	18	56	
98	B	86	68	42	24	17	49	
99	B	89	67	41	22	19	48	
100	A	62	41	32	24	19	36	
101	C	53	36	28	21	17	32	
102	D	89	80	71	60	44	70	
103	B	86	70	56	37	25	58	
104	A	98	96	94	89	69	91	
105	C	64	55	46	40	27	48	
106	E	89	87	85	82	64	82	
107	B	95	89	84	78	60	83	
108	D	63	50	42	34	24	44	
109	A	79	66	57	49	38	59	
110	D	92	86	80	72	48	78	
111	C	84	70	54	36	18	55	
112	D	86	74	57	36	18	57	
113	B	58	42	30	22	18	36	
114	B	98	94	89	76	45	84	
115	A	67	58	46	34	22	47	
116	A	91	75	61	40	23	61	
117	B	92	84	80	63	43	75	
118	E	64	53	43	37	28	47	
119	D	93	85	76	61	35	73	
120	A	61	54	51	50	43	53	

\*Item No. 62 was not scored.

## Section II: Free Response

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### Scoring Guidelines and Sample Student Responses

The answers presented here are actual student responses to the four free-response questions on the 1999 AP Biology Examination. The students gave permission to have their work reproduced at the time they took the exam. These responses were read and scored by the leaders and faculty consultants assigned to each particular question during the AP Reading in June 1999. The actual scores that these students received, as well as a brief explanation of why, are indicated.

**Describe, Explain, Design** — these are the important directives that appear in each of the four FR questions on this year's examination. The questions required students to exhibit higher order thinking skills—not simply learning and feeding back a collection of facts.

- Question 1 is a laboratory/experimental question on photosynthesis that asks students to design an experiment.

- Question 2 is a broad, comprehensive question on the biology of cell-to-cell communication.
- Question 3 is based on analysis of a biological classification scheme, and is basically an evolution and systematic biology question.
- Question 4 deals with how DNA meets the criteria for being hereditary material and asks students to describe experimental evidence supporting one of the criteria.

These four questions covered the breadth of what is typically covered in a two-semester college-level biology course. All four had multiple parts, and there were many ways that students could get full or partial credit. This was an extremely challenging set of FR questions. The diversity of biological facts, mechanisms, and theories was well represented on these exam topics.

## Question 1 Scoring Guidelines

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Question 1 is the laboratory question for 1999; it focuses on **designing** an experiment to test the effects of one of three possible environmental variables on the rate of photosynthesis. After designing the experiment, students are asked to **explain** how they would measure photosynthetic rate in their experiment. The third part of the question asks students to **describe and explain** their expected results. Designing an experiment is not a new task on a free-response question, and the three-part design of the question is typical of such questions in recent AP Biology Exams. The standards were set in such a way that students could garner 7 points for experimental design, 2 points for describing expected results, and 3 points for biological explanation of results. Our typical scoring requires students to get points from all parts of a multipart question before achieving a maximum score of 10.

### A. Experimental Design: (7 points maximum)

The following experimental characteristics may earn 1 point each:

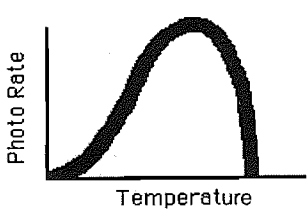
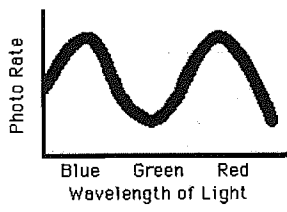
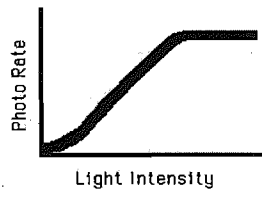
*Score only the **first** independent variable (temperature,  $\lambda$ , intensity) manipulated, and the **first** factor used by the student to measure photosynthetic rate ( $O_2$ ,  $CO_2$ , etc.).*

*A 3-point maximum in Section A if the experiment will not work biologically. Examples: using an organism that is not photosynthetic, or using an apparatus that biologically will not measure photosynthesis as designed (i.e. potometer or respirometer). 0 points lost for a minor flaw in technical design.*

- State **hypothesis** (clear statement of a hypothesis, identifies it as a hypothesis, uses “If/then” statement)
- Specify a **control group** for comparison
- Identify and **hold constant at least one experimental factor** that can affect photosynthetic rate
- Manipulate **the independent variable** (change the temperature,  $\lambda$  of light, intensity of light)
- Describe **what is being measured** to determine rate ( $CO_2$  or  $H_2O$  consumption,  $O_2$  or carbohydrate production, growth,  $e^-$  flow measured with dye reduction, production of an intermediate product, etc.)
- **Quantify** the measurement of the variable (method **and** time frame of measurement)
- Rate calculation or definition
- Verify results through sample size (>1) or repetition
- Utilize **statistical application** of data (mean, t-test, ANOVA, etc.)
- Design an **exemplary** experiment

**B. Describe expected experimental results** (2 points maximum)

- Verbal or graphic description of expected experimental results (1 point)
- Verbal or graphic description of expected results across the entire range of biological activity (1 point)
- The graphs below represent 2-point graphs, but to earn **any** points, graphs must be accurately labeled

Temperature	Wavelength	Intensity
<ul style="list-style-type: none"> <li>• Rate rises with temperature to an optimum and then falls</li> </ul>	<ul style="list-style-type: none"> <li>• An “action spectrum” with highest rates in the blue and red regions of the spectrum</li> </ul>	<ul style="list-style-type: none"> <li>• Rate increases steadily to a maximum and levels off</li> </ul>
 <p>Photo Rate</p> <p>Temperature</p>	 <p>Photo Rate</p> <p>Blue Green Red Wavelength of Light</p>	 <p>Photo Rate</p> <p>Light Intensity</p>

**How students could earn points in this section:**

- One point for a reasonable **description of expected results** from experimental set-up, and a second point if description included what to expect if the independent variable extended across the range of biological activity.
- To earn points for **temperature results**, a photosynthetic rate that rose with temperature to an optimum and then fell. A description or a graph similar to the one in the table above could earn the student 2 points.
- To earn points for **wavelength results**, a photosynthetic rate showing an “action spectrum” with highest rates in the blue and red regions of the spectrum and a pronounced dip in the green. A description or a graph similar to the one in the table above could earn the student 2 points.
- To earn points for **light intensity results**, a photosynthetic rate that rose with temperature to an optimum and then leveled off. A description or a graph similar to the one in the table above could earn the student 2 points.

**C. Biological explanation of results** (3 points maximum)

■ **Temperature**

- Enzyme kinetics or metabolic changes
- Enzyme denatures
- Photorespiration
- Stomatal closing with high temperature, limits CO<sub>2</sub>, and lowers rate
- Excessive water loss, less reactant available for reaction
- Elaboration

■ **Wavelength**

- Absorption/reflection of light by chlorophyll
- Accessory pigments absorbing green light
- Relation between wavelength and energy
- Elaboration

■ **Intensity**

- More photons hit photosystems
- More  $e^-$  flow in the electron transport system/time
- Plateau caused by limiting factors
- Elaboration

**How students could earn points in this section:**

- In this section, students could earn points by giving solid, biological explanations for the changes in photosynthetic rates they would expect.
- The simplest way to earn 2 points was by explaining both the rise and fall of the temperature curve, both “peaks” and the “valley” of the action spectrum, and both the rise and the plateau of the light intensity curve.
- There was also an elaboration point to be given at the readers’ discretion for very strong, in-depth answers.
- Answers were expected to contain some sophistication, and answers such as, “In the high temperature, the plant dies so photosynthesis is lower” or “Since light is important to photosynthesis, with higher intensities, photosynthesis goes faster,” did not receive points.



Sample Student Responses for Free-Response Question 1

Essay 1 (7 points)

\* The affect of light on Green Algae in Photosynthesis

Thesis: If a high intensity light is shown of Green Algae, then more  $O_2$  will be released as a result of increases photosynthesis.

Control: Green Algae in a vile, in room with moderate light

Experimental: Green Algae in a vile with high intensity light shinning on it.

Process: To begin, 2 viles are needed. One lamp, water cooling shield from light, data tables, and a timer are also needed. First, place the same amount of green algae in the two viles which also contain the same amount of water. Room temperature. Place the control group in a moderately lit area. Place the experimental group in front of the heat coolant (water shield) and the lamp on the otherside of the shield. Start the timer and record the number of bubbles of  $O_2$  released from the green algae every 30 seconds. Do this for both viles (control and experimental) at the same time. Three people should be used for this experiment. Continue counting and recording the  $O_2$  bubbles every 30 seconds for 10 minutes.

		<u><math>O_2</math> bubbles/30 seconds</u>							
		30s	60s	90s	120s	150s	180s	210s	240s...
(w/o light)	Vile One: control								
(w/ light)	Vile Two: experimental								

(Table 1 example)

Conclusions: I would expect the  $O_2$  bubble number to be higher for the lit vile than the controlled vile. A graph would show the relationship between the two.

I would expect these results because light is a very important part of photosynthesis... photo = light  
I would also expect the  $O_2$  bubble numbers to decrease after a long time of being exposed to the light because the algae would in time not need to produce much  $O_2$ . it has enough food.

### Commentary on Essay 1

In Part A, points were earned for stating a **hypothesis**, identifying a **control** group for comparison, **eliminating** other variables such as heat, **manipulating** the independent variable, identifying **what** dependent variable is to be measured (oxygen produced), and for **quantifying** not only how (counting bubbles) and when (every 30 seconds) the dependent variable would be measured. In Part B, 1 point was earned for describing expected **results** in a limited way.

## Essay 2 (8 points)

Using sweet pea plants, my experiment would test the ~~old~~ effects of temperature upon the rate of photosynthesis. My hypothesis would be that if ~~a~~ the sweet pea plant grows well in mild, warm conditions, then extremities such as harsh cold or scalding heat will most likely ~~stop~~ <sup>hinder</sup> growth or even kill the plant. I chose sweet pea plants because of their common variety, and ~~the~~ fast rate of growth. Photosynthesis, or the rate ~~measured~~, would be measured by the growth of the plant over a period of time, given that in optimal conditions, sweet pea plants grow ~~the most~~ rapidly.

My experiment would consist of 10 plants, grown from seeds, at each ten point mark on a Fahrenheit thermometer. Therefore, there would be ten test subjects at  $30^{\circ}$ , ten at  $40^{\circ}$ , ten at  $50^{\circ}$ , ten at  $60^{\circ}$ , ten at  $70^{\circ}$ , ten at  $80^{\circ}$ , ten at  $90^{\circ}$ , ten at  $100^{\circ}$ , and ten at  $110^{\circ}$ . At room temperature,  $75^{\circ}\text{F}$ , I would have ten control subjects. Using growth chambers, all plants would receive the same amount of humidity, sunlight, water and soil, with the only variance being temperature in each growth chamber. Each chamber would be set to shed ~~10~~ hours of sunlight upon each plant, much like a common summer day in the temperate zone. Each test subject would be measured in height and observed for heartiness and color on a day to day basis.

My predictions would be that in the growth chambers ~~be~~ set below  $60^{\circ}\text{F}$ , there would be virtually no plant growth. In the chambers set from  $60^{\circ}\text{F}$  to  $90^{\circ}\text{F}$ , maximum growth would be observed. In the control chamber of  $75^{\circ}\text{F}$ , average ~~of~~

optimal growth would be displayed, and in the growth chambers of  $100^{\circ}$  and  $110^{\circ}$ , a decline in growth would be demonstrated. I would expect these results because just as cold temperature may inhibit photosynthesis, and slow down levels of cell reproduction, warmer temperatures may be too harsh for the plant, stripping it of vital water through evaporation.

### Commentary on Essay 2

In Part A, points were earned for stating a **hypothesis**, identifying **what** dependent variable is to be measured (growth), **verifying** the results by using 10 plants in each experimental condition, **manipulating** the independent variable (temperature), **eliminating** other variables ("same amount of humidity, sunlight, water and soil"), and for **quantifying how** (measuring height) and **when** ("day to day") the dependent variable would be measured. In Part B, 2 points were earned for describing expected results **across the range** of biological activity.

### Essay 3 (10 points)

The experiment would test ~~the effect~~ how varying wavelengths of light affect the rate of photosynthesis in a young maple tree. ~~I hypothesize~~ Four young plants would be used, each placed in a glass tank in a black closet. Each closet would have a ventilation system that maintains an air content of 79% nitrogen, 20% oxygen, and ~~to~~ 1% carbon dioxide. The first maple tree (young, so that it would be small and able to fit in the tank that contains ~~it~~<sup>soil</sup> and is open to the air of the closet) would be a control exposed to visible light from a lamp positioned one foot above the plant. The lamp would simulate the sun, giving off a <sup>full</sup> spectrum of wavelengths of light. The second tree would be exposed to red light, set up like the control. The third would be exposed to blue light, and the fourth to green light.

These light wavelengths represent the two ends of the visible light spectrum, while green has a wavelength in between the wavelengths of red (longest) and blue (shortest) ~~(except~~ <sup>with the violet)</sup>. My <sup>first</sup> hypothesis would be that the ~~trees~~ <sup>tree</sup> exposed to blue light would have a higher rate of photosynthesis than the tree exposed to red light. My second hypothesis would be that the tree exposed to green light would have the lowest rate of photosynthesis. My third hypothesis would be that the control exposed to "sunlight" would have the highest rate. Thus, the variable of my experiment would be the wavelength of light.

Each tree would be exposed to its respective light source for three weeks. After this time period, each plant would be ground up and tested for starch content, since photosynthesis produces carbohydrates stored as starch, mostly in the roots but also in the leaves themselves. A simple test could be to use iodine, which detects the presence of starch, although it is likely that all four plants would contain some starch. ~~If the~~ To really ~~find the~~ measure the rate of photosynthesis, the specific number of grams of starch should be found by analyzing the plant content. ~~Before beginning the~~

I would expect the tree exposed to the full spectrum of light to have the highest rate of photosynthesis because the light-absorbing pigments in a plant chloroplast differ in which wavelengths of light they absorb. Chlorophyll a absorbs light of

wavelength 700 and 680 nm, while other pigments like chlorophyll b absorbs light of different wavelengths to use as energy for photosynthesis. Either the red or blue-light exposed tree would have the next highest starch content because chlorophyll tends to have the highest absorption of light of these wavelengths. Finally, I would expect the tree exposed to green light to wither and die because chlorophyll, a green pigment, reflects green light rather than absorbs it. The energy is not taken in, so this tree cannot ~~per~~ carry out photosynthesis. It would have the lowest starch content of the four plants. The overall order, from highest to lowest, of photosynthesis rates would be: control, red or blue, green. This experiment should be repeated numerous times - at least 50 - to prove its validity. Though maple trees are apt specimens because of their broad leaves and tap roots, the experiment should be tried with maple seeds from the beginning as well as starting with young plants.

### Commentary on Essay 3

In Part A, points were earned for, **eliminating** other variables by keeping gas concentrations constant, identifying a **control** group for comparison, stating a **hypothesis**, **manipulating** the independent variable (starch content), for **quantifying** *how* (measuring the grams of starch) and *when* ("over three weeks") the dependent variable would be measured, and **verifying** the results by repeating the procedure. In Part B, 1 point was earned for describing expected **results** in a limited way (full spectrum sunlight with the highest rate), and 1 point for describing expected results **across the range** of the light spectrum. In Part C, a point was earned for a good **explanation** of light absorption and reflection by chlorophyll.

## Common Errors and Misconceptions

### Part A

- Most students failed to earn the “Quantify” point because they did not explain how to measure gases like oxygen and carbon dioxide; when they did, they failed to describe the time frame in which the gases would be measured.
- Few students earned points for a rate calculation/definition, using a statistical application, or designing an exemplary experiment.
- Students often used equipment from other AP Laboratory protocols such as potometers and respirometers.
- A widely held misconception is that transpiration rate equals photosynthetic rate.
- Another misconception is that light duration and light intensity are the same.
- Many students who sought to measure plant growth and used darkness as a control or simply a light intensity treatment failed to realize that plants can grow vigorously in the dark.
- Often students chose to measure photosynthetic rate by examining the “health” of the plant.

### Part B

- Most students seemed unaware of the temperature curve going down and the light intensity curve leveling off at higher temperatures.

### Part C

- Generally, students garnered few points in this section, which relied almost entirely on basic AP-level biological knowledge.
- Students had difficulty explaining results, especially when they tried to relate reaction rate to the events in the “light phase” of photosynthesis. They seemed to do a little better relating the lowered kinetic energy of reactants at low temperature and the denaturing of enzymes at higher temperature.
- Very few student essays combined strong experimental designs with an in-depth knowledge of photosynthesis.

### What Can Teachers Do to Improve Performance on This Type of Question?

Responses to this question indicate that students, in general, need to learn how to design experiments well. Therefore, AP Biology teachers should take additional time to teach basic research design. There is also some evidence indicating that more advanced coverage of photosynthesis should be taught in AP classes.

Students should perform all the AP labs and teachers should relate what is going on in the lab more closely to class content areas. After each AP lab exercise is completed, teachers should include discussions or questions for their students. These questions should be designed to help students apply the lab protocol to other experiments.



## Question 2 Scoring Guidelines

Question 2 is a four-part question about different kinds of communications between cells in multicellular organisms. Students are expected to write on three categories, **describing** the communications that occurs. One choice is communication between plant cells, and the other three choices involve communication between cells found in animals. For one of these, students have the option of choosing between neuron-to-neuron and neuron-to-muscle-cell communication.

For scoring student essays, a simple template for determining the distribution of points was developed, along with a ten-page addendum covering the details of plant cell communication, immune system cell communication, neuron-to-neuron/neuron-to-muscle-cell communication, and specific endocrine gland-to-target-cell communications. The complexity inherent in the immune system and the endocrine system necessitated these extremely detailed and lengthy standards. This broad question gave students an opportunity to demonstrate factual knowledge gained during their AP Biology course, while allowing students to choose the type of cell communication with which they were most familiar.

Students could earn a maximum of 4 points within a category. This ensured that three categories must be addressed in order for the student to be able to earn a grade of ten for this essay. The 4 points were distributed as follows:

- one (1) point maximum for describing the **source** cell
- one (1) point maximum for describing the **signal**
- two (2) points maximum for describing **responses** elicited

These latter 2 points could be earned by describing two different responses (2 response points), or by describing 1 response in detail (1 response point and 1 elaboration point). Elaboration points could not be earned for describing source or signal, except as noted in the guidelines.

### Template for Determining the Distribution of Points

	<b>Source</b> [1 point maximum]	<b>Signal</b> [1 point maximum]	<b>Responses/Elaborations</b> [2 points maximum]
<b>Communication between two plant cells</b> [4 points maximum]	Hormone-producing cell (generic) Plasmodesmata (elaboration point for good description)	A specific plant hormone	Various physiological changes Ion movement; H <sub>2</sub> O movement; RNA movement

#### How students could earn points in this section:

##### *Plant Hormonal Communication*

- **Source point** could be earned by a phrase such as “hormone-releasing cell.” This is due to the fact that plant hormones are often produced in multiple locations, e.g., various meristems.
- **Signal point** could be earned only by naming a specific plant hormone (auxin, gibberellin, etc.).
- **Response point(s)** could be earned by naming any of the general or specific effects associated with the hormone chosen.

##### *Plant Non-Hormonal Communication*

- **Source point** could be earned by a description of a plasmodesma.
- **Source-elaboration point** could be earned by a more detailed description of such; no points were earned for simple use of the term plasmodesma without an accompanying description.
- **Response point(s)** could be earned by identifying specific responses that result from communication via plasmodesmata.



The standards also incorporated opportunities for earning points for such examples as phytochrome-mediated communication, communication involved in touch-sensitive plants, etc.

<b>Communication between two immune system cells</b> [4 points maximum]	Any two immune system cells interacting or An immune system cell interacting with the product of another immune system cell	T <sub>c</sub> /APC docking Antibody Histamine Interferon	Discharge of perforin; phagocytosis of pathogen; inflammatory response; phagocyte activation; Ab secretion; clonal selection
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**How students could earn points in this section:**

Typically, two immune-system cells will initially interact (e.g., T<sub>H</sub> docking with an APC), setting off a sequence of events involving an early release of lymphokines/interleukins that elicit multiple effects such as activation of other immune-system cells. In turn, one of the initial cells may subsequently interact with a different type of immune-system cell (e.g., T<sub>H</sub> docking with a B cell, for a T-dependent antigen), mediating release of additional lymphokines/interleukins that elicit still other effects. And so, there are initial sources/signals/responses, intermediate sources/signals/responses, and late-term sources/signals/responses.

*A student could earn points by starting anywhere in the sequence and describing the interaction of any immune-system cell with another immune-system cell.*

The definition of what constitutes an immune-system cell is not static. For example, an uninfected epithelial cell would not be considered an immune system cell, whereas that same cell infected by a virus would be considered an immune system cell, given that it releases interferons, one of whose effects is to activate phagocytes. Interactions between an immune-system cell and the products of another immune-system cell (e.g., the phagocytosis by a macrophage of an Ab-bound pathogen) also fell within the parameters of the question.

<b>Communication between two neurons</b> <b>OR</b>	Sending neuron	Neurotransmitter	Chemical gating; depolarization of postsynaptic membrane; EPSP, IPSP, or both
<b>between a neuron and a muscle cell</b> [4 points maximum]	Sending neuron	Neurotransmitter	Action potential to T tubules; Ca <sup>++</sup> release from sarcoplasmic reticulum; Ca <sup>++</sup> binding to troponin; cross-bridge formation

**How students could earn points in this section:**

***Neuron-to-Neuron Communication***

- source point for a description of a sending neuron, i.e., one involved in transmitting a signal across a chemical or electrical synapse.
- signal point for describing a generic neurotransmitter (in the case of chemical synapses) or for describing direct current flow (in the case of electrical synapses utilizing a gap junction).
- response points, any of the various effects elicited in the post-synaptic neuron could earn up to 2 points.

***Neuron-to-Muscle-Cell Communication***

- The criteria of a sending neuron and a neurotransmitter were the same as described for neuron-to-neuron communication.

- Up to 2 response points for any of the various effects elicited in the muscle fiber, whether initial, intermediate, or late-term. It should be noted that most students, in designating a muscle fiber, did not specify skeletal, cardiac, or smooth muscle; the standards attempt to encompass all of these.

Communication between a specific endocrine-gland cell and its target cell [4 points maximum]	Specific gland (elaboration point for peptide vs. steroid hormone pathways)	Specific hormone	Specific effect
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**How students could earn points in this section:**

The precise wording of the question required specificity and linkage for the answer to earn points.

- A **signal** point could not be earned in the absence of a **source point** or a **response** point. Thus, a student who described an endocrine gland as releasing a mismatched hormone (e.g., pituitary → aldosterone) earned nothing; whereas a student who described an endocrine gland with its correctly matched hormone (e.g., pineal gland → melatonin) earned two points, i.e., for source and signal. Likewise, a hormone had to be linked to responses it actually elicits to earn response points. Points could be earned for initial, intermediate, or long-term responses.
- It was also possible to earn a source point and response points by correct linkage, even in the absence of a signal point (e.g., the pituitary causing ovarian follicle growth without mention of FSH).
- Correct linkage between source–signal–responses was necessary for a student to earn four points in this category.
- Points were awarded if a student designated “the pituitary” as the source for FSH or prolactin, without designating the anterior lobe specifically. Likewise for “the adrenal” as the source of hormones from the adrenal medulla and the adrenal cortex. However, if a student attributed a hormone of the adrenal medulla to the adrenal cortex, no points were earned.
- Although many non-steroid hormones may eventually be found to involve a signal transduction pathway that includes a second messenger, a point was awarded only for those hormones that have been identified as having such a second messenger in the textbooks and reference works available to the readers.
- In addition, a student could earn up to 4 points for an accurate description and linkage of an endocrine gland, hormone, and responses from an invertebrate, although such answers were very rare.

**Addendum: Details of Communications between Cells in Multicellular Organisms**

**Part I – Plant cell-to-plant cell communication**

**Plant hormonal communication**

Source:	Signal:	Response/Recipient Cell:
Apical bud/young leaves	<b>Auxin (IAA)</b>	<ul style="list-style-type: none"> <li>■ cell elongation</li> <li>■ increase in cell wall plasticity</li> <li>■ stimulation of proton pumps/lowering of cellular pH</li> <li>■ stem elongation</li> <li>■ root growth/differentiation</li> <li>■ stem phototropism (+), root phototropism (–)</li> <li>■ stem gravitropism (–), root gravitropism (+)</li> <li>■ suppression of lateral buds (apical dominance)</li> <li>■ organogenesis</li> </ul>
Seed	<b>Auxin (IAA)</b>	<ul style="list-style-type: none"> <li>■ cell elongation</li> <li>■ seed germination</li> <li>■ fruit development</li> </ul>

<b>Source:</b> Root cells	<b>Signal:</b> <b>Cytokinin</b>	<b>Response/Recipient Cell:</b> <ul style="list-style-type: none"> <li>■ root growth/differentiation</li> <li>■ cell division (general effect)</li> <li>■ delay of senescence (particularly in leaves)</li> <li>■ organogenesis</li> </ul>
Seed hypocotyl	<b>Cytokinin</b>	<ul style="list-style-type: none"> <li>■ cell division (general effect)</li> <li>■ seed germination</li> </ul>
<b>Source:</b> Apical bud meristem Root meristem Young leaves	<b>Signal:</b> <b>Gibberellins</b>	<b>Response/Recipient Cell:</b> <ul style="list-style-type: none"> <li>■ bud growth (including breaking of lateral bud suppression)</li> <li>■ stem elongation</li> <li>■ root growth</li> <li>■ root differentiation</li> <li>■ leaf growth</li> <li>■ flowering</li> <li>■ bolting</li> <li>■ fruit development</li> </ul>
Seed embryo	<b>Gibberellins</b>	<ul style="list-style-type: none"> <li>■ stimulation of aleurone cells to release hydrolytic enzymes</li> <li>■ endosperm breakdown</li> <li>■ seed germination</li> </ul>
Older tissue Water-stressed tissue Unripe fruits	<b>Abscisic acid</b>	<ul style="list-style-type: none"> <li>■ growth inhibition</li> <li>■ closing of stomata</li> <li>■ reinforcement of seed dormancy</li> <li>■ stress responses</li> </ul>
Ripening fruits Stems Older leaves Flowers	<b>Ethylene</b>	<ul style="list-style-type: none"> <li>■ promotion of fruit ripening (autocatalytic)</li> <li>■ hypocotyl hook formation</li> <li>■ inhibition of cell elongation</li> <li>■ root growth/inhibition (dose- and species-dependent)</li> <li>■ leaf growth/inhibition (dose- and species-dependent)</li> <li>■ flower growth/inhibition (dose- and species-dependent)</li> <li>■ leaf abscission</li> </ul>
Wounded tissue Infected tissue	<b>Ethylene</b>	<ul style="list-style-type: none"> <li>■ stimulation of suberin deposition (physical barrier to pathogens)</li> <li>■ stimulation of phytoalexin biosynthesis (chemical barrier to pathogens)</li> <li>■ potentiation of hypersensitive response</li> </ul>

**Note:** A description of phytochrome-mediated responses (e.g., flowering, etc.) can also earn up to 4 points in this category.

<b>Plant non-hormonal communication</b>		
<b>Source:</b>	<b>Signal:</b>	<b>Response/Recipient Cell:</b>
Plasmodesmata (elaboration point for good description)		<ul style="list-style-type: none"> <li>■ water movement</li> <li>■ ion movement</li> <li>■ movement of informational molecules, e.g., RNA</li> </ul>
Mimosa leaves/pulvini Venus flytrap sensory hairs	<b>K<sup>+</sup> movement</b>	<ul style="list-style-type: none"> <li>■ loss of turgor</li> <li>■ propagation of action potentials in plant</li> </ul>

Addendum, *continued*

**Part II – Immune-system-cell to immune-system-cell communication**

**Interferon release by virus-infected cells** (infected cell becomes immune system cell)

Source:	Signal:	Response/Recipient Cell:
Virus-infected cells	<b>Interferon</b>	<ul style="list-style-type: none"> <li>■ activation of phagocytes</li> <li>■ resulting ingestion of microbes</li> </ul>

**Cytotoxic T cell ( $T_C$ ) “docking with” antigen-presenting cell** (APC = cell infected with intracellular pathogen or a cancer cell)

Source:	Signal:	Response/Recipient Cell:
APC	<b><math>T_C</math>/APC docking</b>	<ul style="list-style-type: none"> <li>■ discharge of perforin by <math>T_C</math></li> <li>■ pore formation in cell membrane of infected cell</li> <li>■ cell lysis</li> </ul>

**Helper T cell ( $T_H$ ) “docking with” antigen-presenting cell** (APC = macrophage)

Source:	Signal:	Response/Recipient Cell:
APC	<b><math>T_H</math>/APC docking</b>	<ul style="list-style-type: none"> <li>■ release of IL-1/cytokines by APC</li> <li>■ <math>T_H</math> activation</li> <li>■ release of IL-2/cytokines by <math>T_H</math> cell</li> <li>■ <math>T_H</math> proliferation (mediated by IL-2)*</li> <li>■ formation of memory <math>T_H</math> clone (mediated by IL-2)*</li> <li>■ <math>T_C</math> activation (med. by IL-2; CMI)</li> <li>■ B cell activation (mediated by IL-2; AMI/humoral immunity)</li> <li>■ “docking” of <math>T_H</math> with a B cell (for T-dependent Ag)</li> <li>■ formation of plasma B cell clone*</li> <li>■ formation of memory B cell clone*</li> <li>■ antibody secretion (primary immune response)</li> <li>■ development of immunological memory</li> </ul> <p>*Part of clonal selection</p>

**Macrophage interaction with neutralized or agglutinated (antibody-bound) pathogen**

Source:	Signal:	Response/Recipient Cell:
Macrophage	<b>Antibody</b>	<b>Macrophage activation</b> <ul style="list-style-type: none"> <li>■ phagocytosis of pathogen</li> </ul>

**Macrophage interaction with Ab-precipitated soluble antigen**

Source:	Signal:	Response/Recipient Cell:
Macrophage	<b>Antibody</b>	<ul style="list-style-type: none"> <li>■ macrophage activation</li> <li>■ phagocytosis of antigen</li> </ul>

Source:	Signal:	Response/Recipient Cell:
Mast cell	<b>Histamine</b>	<ul style="list-style-type: none"> <li>■ inflammatory response</li> <li>■ chemotaxis</li> <li>■ recruitment of phagocytes</li> </ul>

### Part III – Communication between two neurons OR between a neuron and a muscle cell

#### Neuron-to-neuron transmittance of an action potential via neurotransmitter release at chemical synapse

Source:	Signal:	Response/Recipient Cell:
Pre-synaptic neuron	Neurotransmitter	<ul style="list-style-type: none"><li>■ binding to postsynaptic membrane</li><li>■ opening or closing of ion channels in postsynaptic membrane (chemical gating)</li><li>■ change in membrane potential in postsynaptic membrane (graded potential; may be EPSP, IPSP, or both)</li><li>■ depolarization or hyperpolarization (opening or closing of ion channels) of postsynaptic membrane</li><li>■ possible action potential in postsynaptic cell</li><li>■ rapid enzymatic degradation of neurotransmitter</li><li>■ spatial summation (multiple presynaptic neurons stimulating a postsynaptic neuron simultaneously)</li><li>■ temporal summation (a single presynaptic neuron stimulating a postsynaptic neuron in rapid-fire sequence)</li></ul>

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#### Pre-gap neuron to-post-gap neuron transmittance of an action potential via gap junctions (electrical synapses)

Source:	Signal:	Response/Recipient Cell:
Pre-synaptic neuron	Current flow	<ul style="list-style-type: none"><li>■ rapid depolarization of postsynaptic neuron</li><li>■ maintenance of signal strength</li><li>■ synchronization of vertebrate neuronal responses</li></ul>

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#### Release of acetylcholine at neuromuscular junction

Source:	Signal:	Response/Recipient Cell:
Pre-synaptic neuron	Acetylcholine	<ul style="list-style-type: none"><li>■ depolarization of muscle fiber plasma membrane</li><li>■ action potential carries to T-tubules</li><li>■ Ca<sup>++</sup> release from sarcoplasmic reticulum</li><li>■ Ca<sup>++</sup> binding to troponin</li><li>■ conformational change of tropomyosin</li><li>■ exposure of myosin binding sites</li><li>■ cross-bridge formation</li><li>■ muscle fiber contraction</li><li>■ cholinesterase termination of response</li></ul>

**Note:** An accurate description of events at a neuromuscular junction involving cardiac muscle or smooth muscle can earn up to 4 points in this category.

**Note:** Components of a reflex arc may be described under either neuron-to-neuron communication, or neuron-to-muscle cell communication. However, a portion of the reflex arc must be isolated and described on the basis of two individual cells communicating, viz., either one neuron with another neuron, or a neuron with a muscle fiber.

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### Part IV – Endocrine-gland-cell to target-tissue-cell communication

#### Hypothalamic/Posterior Pituitary Hormones

Source:	Signal:	Response/Recipient Cell:
Hypothalamic/Posterior Pituitary Hormones	ADH (vasopressin)	<ul style="list-style-type: none"><li>■ second messenger, e.g., cAMP</li><li>■ increased water reabsorption by collecting duct</li><li>■ urine concentration/osmoregulation</li><li>■ vasoconstriction increases BP</li></ul>
Hypothalamic/Posterior Pituitary Hormones	Oxytocin	<ul style="list-style-type: none"><li>■ increased uterine contraction</li><li>■ increased milk ejection/letdown</li></ul>

**Addendum, continued**

**Hypothalamic Hormones**

Source:	Signal:	Response/Recipient Cell:
Hypothalamus	<b>Releasing hormone</b>	<ul style="list-style-type: none"> <li>■ increased hormone secretion by anterior pituitary (adenohypophysis)</li> <li>■ second messenger, e.g., cAMP</li> <li>■ see specific anterior pituitary hormones for additional effects</li> </ul>
Hypothalamus	<b>Inhibiting hormone</b>	<ul style="list-style-type: none"> <li>■ decreased hormone secretion by anterior pituitary</li> <li>■ see specific anterior pituitary hormones for additional effects</li> </ul>

**(Anterior) Pituitary Tropic Hormones**

Source:	Signal:	Response/Recipient Cell:
Anterior pituitary	<b>FSH</b>	<ul style="list-style-type: none"> <li>■ increased follicular growth (granulosa cells)</li> <li>■ increased estrogen release by growing follicle</li> <li>■ second messenger, e.g., cAMP</li> <li>■ negative feedback of further FSH and LH release by estrogen</li> <li>■ increased sperm production in males (Sertoli cells)</li> </ul>
Anterior pituitary	<b>LH</b> <b>(ICSH in males)</b>	<ul style="list-style-type: none"> <li>■ increased follicular maturation</li> <li>■ ovulation</li> <li>■ promotes formation/maintenance of corpus luteum</li> <li>■ increased gonadal steroid secretion by ovaries/testes</li> <li>■ second messenger, e.g., cAMP</li> </ul>
Anterior pituitary	<b>TSH (thyrotropin)</b>	<ul style="list-style-type: none"> <li>■ increased hormone production/secretion by thyroid</li> <li>■ increased thyroid growth</li> <li>■ second messenger, e.g., cAMP</li> </ul>
Anterior pituitary	<b>ACTH</b>	<ul style="list-style-type: none"> <li>■ increased release of adrenal steroids</li> <li>■ second messenger, e.g., cAMP</li> </ul>
Anterior pituitary	<b>Growth hormone (STH)</b>	<ul style="list-style-type: none"> <li>■ growth stimulation (bone/muscle)</li> <li>■ increased protein synthesis</li> <li>■ alters metabolism</li> </ul>

**(Anterior) Pituitary Nontropic Hormones**

Anterior pituitary	<b>Prolactin</b>	<ul style="list-style-type: none"> <li>■ increased mammary gland growth/maturation</li> <li>■ increased milk production/synthesis</li> <li>■ increased nest building</li> <li>■ decreased LH secretion in males</li> </ul>
Anterior pituitary	<b>MSH</b>	<ul style="list-style-type: none"> <li>■ stimulation of melanocytes</li> <li>■ second messenger, e.g., cAMP</li> </ul>

**Thyroid Hormones**

Source:	Signal:	Response/Recipient Cell:
Thyroid	<b>Triiodothyronine/ thyroxine (T3/T4)</b>	<ul style="list-style-type: none"> <li>■ metabolic stimulation required for development/growth</li> </ul>
Thyroid	<b>Calcitonin</b>	<ul style="list-style-type: none"> <li>■ increased bone formation</li> <li>■ decreased blood calcium/maintenance of homeostasis</li> <li>■ second messenger, e.g., cAMP</li> </ul>

**Parathyroid Hormone**

Source:	Signal:	Response/Recipient Cell:
Parathyroid glands	<b>Parathyroid hormone (PTH)</b>	<ul style="list-style-type: none"> <li>■ increased blood calcium/maintenance of homeostasis</li> <li>■ increased calcium reabsorption by kidneys</li> <li>■ increased calcium absorption by GI tract</li> <li>■ second messenger, e.g., cAMP</li> </ul>

### **Pancreatic Hormones**

<b>Source:</b> Pancreas	<b>Signal:</b> <b>Insulin</b>	<b>Response/Recipient Cell:</b> <ul style="list-style-type: none"><li>■ maintenance of blood glucose uptake/metabolism</li><li>■ increased glucose conversion to glycogen</li></ul>
Pancreas	<b>Glucagon</b>	<ul style="list-style-type: none"><li>■ increased glycogen breakdown to glucose</li><li>■ second messenger, e.g., cAMP</li></ul>
Pancreas	<b>Somatostatin</b>	<ul style="list-style-type: none"><li>■ inhibition of insulin and glucagon release</li><li>■ decreased digestive tract activity</li></ul>

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### **Adrenal (Medulla) Hormones**

<b>Source:</b> Adrenal medulla	<b>Signal:</b> <b>(Nor)epinephrine</b>	<b>Response/Recipient Cell:</b> <ul style="list-style-type: none"><li>■ glycogen breakdown</li><li>■ increased blood pressure</li><li>■ increased breathing rate</li><li>■ increased metabolic rate</li><li>■ fight or flight → changes in blood distribution</li><li>■ second messenger, e.g., cAMP</li></ul>
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### **Adrenal (Cortex) Hormones**

<b>Source:</b> Adrenal cortex	<b>Signal:</b> <b>Glucocorticoid</b> (cortisol)	<b>Response/Recipient Cell:</b> <ul style="list-style-type: none"><li>■ increased protein/fat conversion to glucose</li><li>■ increased blood glucose</li><li>■ immune system suppression</li><li>■ suppression of inflammation</li></ul>
Adrenal cortex	<b>Mineralocorticoid</b> (aldosterone)	<ul style="list-style-type: none"><li>■ increased water reabsorption by kidney</li><li>■ increased Na<sup>+</sup> reabsorption by kidney</li><li>■ increased excretion of K<sup>+</sup></li><li>■ maintenance of mineral (electrolytes) homeostasis</li></ul>
Adrenal cortex	<b>Sex hormones</b>	See androgens and estrogens below

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### **Gastrointestinal Hormones**

<b>Source:</b> Stomach	<b>Signal:</b> <b>Gastrin</b>	<b>Response/Recipient Cell:</b> <ul style="list-style-type: none"><li>■ increased food digestion by stomach</li></ul>
Small intestine	<b>Secretin</b>	<ul style="list-style-type: none"><li>■ increased HCO<sub>3</sub><sup>-</sup> secretion by pancreas</li></ul>
Small intestine	<b>Cholecystokinin</b>	<ul style="list-style-type: none"><li>■ release of pancreatic enzymes</li><li>■ increased gall bladder contractions</li></ul>
Small intestine	<b>Enterogastrone</b>	<ul style="list-style-type: none"><li>■ alters intestinal segmentation</li></ul>

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### **Pineal Gland Hormone**

<b>Source:</b> Pineal Gland	<b>Signal:</b> <b>Melatonin</b>	<b>Response/Recipient Cell:</b> <ul style="list-style-type: none"><li>■ regulation of circadian rhythms</li><li>■ control of puberty onset</li></ul>
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**Addendum, continued**

**Gonadal Hormones**

<b>Source:</b>	<b>Signal:</b>	<b>Response/Recipient Cell:</b>
Testes	<b>Androgens</b>	<ul style="list-style-type: none"><li>■ maintenance of male sexual behavior</li><li>■ male secondary sex characteristics</li><li>■ sperm production</li></ul>
Ovaries	<b>Estrogens</b>	<ul style="list-style-type: none"><li>■ maintenance of female sexual behavior</li><li>■ female secondary sex characteristics</li><li>■ growth of uterine lining</li><li>■ mammary gland growth/differentiation</li></ul>
Ovaries	<b>Progesterone</b>	<ul style="list-style-type: none"><li>■ growth of uterine lining</li><li>■ mammary gland growth/differentiation</li></ul>

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**Kidney and Liver Hormones**

<b>Source:</b>	<b>Signal:</b>	<b>Response/Recipient Cell:</b>
Kidney/Liver	<b>Renin/Angiotensin II system</b>	<ul style="list-style-type: none"><li>■ angiotensinogen → angiotensin I → angiotensin II</li><li>■ increased thirst</li><li>■ increased vasoconstriction</li><li>■ increased aldosterone</li></ul>
Kidney	<b>Erythropoietin</b>	<ul style="list-style-type: none"><li>■ increased erythropoiesis</li><li>■ increased O<sub>2</sub>-carrying capacity of blood</li></ul>
Kidney	<b>Vitamin D (calcitriol)</b>	<ul style="list-style-type: none"><li>■ increased uptake of Ca<sup>++</sup> by gut</li></ul>

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**Thymus Hormone**

<b>Source:</b>	<b>Signal:</b>	<b>Response/Recipient Cell:</b>
Thymus	<b>Thymosin</b>	<ul style="list-style-type: none"><li>■ increased T-lymphocyte activity</li></ul>

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**Embryonic Hormone**

<b>Source:</b>	<b>Signal:</b>	<b>Response/Recipient Cell:</b>
Embryo	<b>Human Chorionic Gonadotropin (HCG)</b>	<ul style="list-style-type: none"><li>■ maintenance of estrogen secretion by corpus luteum</li><li>■ maintenance of progesterone secretion by corpus luteum</li></ul>

**Note:** An accurate description of an endocrine gland, hormone, and responses from an invertebrate organism can earn up to four (4) points in this category.

**Note:** An accurate description of the basis for specificity in the binding of a particular hormone to its target cell will earn a response point.

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## Sample Student Responses for Free-Response Question 2

### Essay 1 (7 points)

Neurons communicate through the events which occur at synaptic vesicles. When a presynaptic cell is stimulated by the nerve impulse, voltage gated protein channels open in the cell's membrane and allow for the influx of  $Ca^{2+}$  ions. This in turn causes the packaging of synaptic vesicles by the Golgi body. These vesicles pass across the synapse and onto the postsynaptic cell. The neurotransmitters of these molecules lead to receptor mediated response by the post-synaptic cell. They fit into <sup>specific</sup> receptors of this cell and cause for the vesicles to be carried into this cell. By therefore transporting its ionic contents to the new cell it ~~carries out the~~ ~~ne~~ creates a concentration gradient which propagates the nerve impulse. Thus, the impulse from the dendrite of a neuron is carried across the synapse and if sufficient it ~~is~~ ~~is~~ (meeting the threshold requirement) the nerve impulse is continued.

The <sup>anterior</sup> pituitary gland produces a hormone known as TSH - thyroid stimulating hormone. This tropin molecule stimulates the ~~produce~~ the thyroid to produce thyroxin which inturn increases metabolic activities within the body. Through a negative feedback the brain is able to sense the levels of metabolic activity throughout the body. When these levels are too high it ~~s~~ decreases the production of TSH.

and thus reduces metabolic levels.

Immune-system cells communicate through receptor mediated endocytosis. As antibodies are produced they bind with the receptor proteins in the membrane of other immune cells. It causes endocytosis to occur and the material is then transported into the cell.

#### Commentary on Essay 1

Points were earned as follows: a **source** point for identifying the pre-synaptic neuron, a **signal** point for a generic neurotransmitter, a **response** point for neurotransmitter binding at the post-synaptic membrane, a **source** point for the pituitary, a **signal** point for TSH, a **response** point for thyroxin production by the thyroid, and an **elaboration** point for a description of feedback control.

## Essay 2 (8 points)

Two immune system cells that must communicate are macrophages and B cells. When a macrophage encounters and kills an invading virus, it must "warn" B cells of the virus' presence so antibodies can be formed and a humeral response mounted. The macrophage presents some of the viral proteins on its surface, along with its usual MHC proteins. Communication to the B cell actually occurs via a helper T cell, which recognizes and attaches to the MHC-antigen complex on the macrophage. Signaling proteins are then released, including the interleukins, and the B cell is summoned and can then produce antibodies to the antigens displayed by the macrophage.

Neurons communicate with each other at synapses by use of neurotransmitters. When an action potential reaches the synaptic terminals of one neuron, it must be sent on to the next neuron across a synapse. The action potential signals an influx of calcium into the presynaptic neuron (the one currently having the action potential). The calcium binds to neurotransmitter vesicles, causing them to fuse with the cell membrane and spill neurotransmitters into the synapse (space between the pre- and post-synaptic neurons). Neurotransmitters can take many forms, including proteins, amino acids, and derivatives of amino acids. The neurotransmitters bind to receptors on the surface of the postsynaptic neuron (the one that is to receive the message) and either stimulate an action potential - by opening sodium channels to depolarize the neuron's membrane - or inhibit one - by hyperpolarizing the membrane.

The cell of an endocrine gland produces a hormone, a chemical meant to affect specific cells in a remote location. The hormone is carried through the bloodstream until it reaches the target cell, which has receptors on its surface that bind to the hormone. If the hormone is a steroid (lipid-based), the hormone-receptor complex enters the cell and goes into the ~~mito~~ nucleus.

Here, it promotes or inhibits the transcription of a certain gene or genes. If the hormone is a peptide (protein-based), it remains on the surface of the cell and initiates a ~~secreted~~ signal transduction pathway. A cascade of chemical events, involving secondary and possibly tertiary messenger molecules, elicits the desired response - usually activation or deactivation of a pre-existing protein.

### Commentary on Essay 2

Points were earned as follows: a **source** point for antigen presentation by a macrophage; a **signal** point for interleukin release; a **response** point for antibody secretion by B cells; a **source** point for the presynaptic neuron; a **signal** point for a generic neurotransmitter; a **response** point for neurotransmitter binding at the postsynaptic membrane; a **response** point for the opening of Na<sup>+</sup> channels in the post-synaptic membrane; and a **response** point for a signal transduction pathway.

## Essay 3 (10 points)

Communication between two immune-system cells is achieved through binding on releasing chemicals. For example, a viruses infected cell can act as a antigen presenting cell and put a piece of the epitope on its cell membrane (combined with a class one MHC protein). When ~~kill~~ a partially activated killer T cell (Tc cell) comes, it binds to the virus, infected cell and is completes its activation. Also, when macrophage is activated during humoral immune response, it releases ~~interferon~~ interleukin 1 to signal ~~the~~ T helper T cells.

The results of those communications are:

1. The activation of ~~set~~ certain immune cells in order to destroy the antigen
2. To enable ~~the~~ cells like ~~#~~ Tc cells to ~~recognize~~ recognize the antigen.

Communication between two neurons is when they conduct a nerve impulse. When a nerve impulse arrives at the presynaptic membrane, the membrane ~~is~~ becomes permeable to  $Ca^{2+}$  so  $Ca^{2+}$  ions diffuses into the terminal knob and activate ~~micro~~ microfillaments inside that can creat current to draw synaptic vesicles close to the membrane. Then, the synaptic vesicles ~~are~~ fuse with the membrane, releasing neurotransmitters into the synaptic cleft. Neurotransmitters diffuse across the synaptic cleft and bind to receptors on the post synaptic membrane causing  $Na^+$  gates to open. If enough  $Na^+$  gates open to reach the membrane

threshold, <sup>a</sup> nerve impulse will be conducted by the second neuron.

Communication between an endocrine-gland cell and its target cell is achieved through chemicals (hormones). When sensory receptors are stimulated, they send impulses to the control center which direct the adaptive responses. ~~If~~ Endocrine glands can be the effectors. When, <sup>a</sup> endocrine gland is stimulated, the cells produce ~~or~~ <sup>or</sup> release hormones. If the hormone is made of proteins, it will bind to ~~a~~ receptors on the target cell ~~and~~ and will activate a series of enzyme catalysed reactions to cause changes in its metabolic rate. If the hormone is a steroid, it will pass through the cell membrane of the target cell, bind to receptors in the cytoplasm and with the receptor enters the nucleus causing changes in gene expression.

The types of responses that result from this communication depend on types of the endocrine gland cell and its target cell. For example, thyroxin produced by thyroid gland cause an increase in metabolic rate in the target cell. Follicle Stimulating Hormone produced by anterior pituitary cause the follicles in ovaries to develop. (in female of course). ~~If~~

### Commentary on Essay 3

Points were earned as follows: a **source** point for antigen presentation; a **signal** point for  $T_C$ -APC binding; a **response** point for the completion of  $T_C$  activation; a **response** point for  $T_H$  recruitment; a **source** point for the pre-synaptic neuron; a **signal** point for a generic neurotransmitter; a **response** point for the opening of  $Na^+$  channels in the post-synaptic membrane; a **response** point for steroid vs. non-steroid pathways, a **signal** point for thyroxin; and a **source** point for the thyroid.

## Common Errors and Misconceptions

Answers often incorporated vague phrases such as “cells talking to each other,” “messages traveling along pathways,” “signals sent and received,” etc., without any mechanistic explanation of how any of this occurred. Many students wrote of cell membrane receptors while rarely linking these receptors to a signal coming from another cell; reflecting an imprecise reading of the question.

### Plant Communication

- Students often were unable to associate a response to the hormone that elicits it.
- Many students wrote (for no credit) of communication between guard cells and stomates, between source cells and sink cells, and between xylem cells.

### Immune-System Communication

- Students were unable to sort out the complexity of what cells interact with what other cells.
- General statements of “B cells talking to T cells,” “antibodies protecting the body against disease,” and “the immune system’s ability to distinguish self from non-self” were frequent.
- Many students wrote of an immune-system cell interacting with a virus or bacterium without relating this response to a signal from another immune system cell.

### Neuron-to-Neuron Communication

- While students often were able to describe the idea of a sending cell and the idea of a neurotransmitter, their descriptions of events in the postsynaptic neuron were lacking in specificity.

- Statements such as “the neuron gets the message” were common.
- Students often stated incorrectly that an action potential originates at an axon, travels through the cell body, and terminates at a dendrite, where it is transmitted to the next neuron.
- Many students described the propagation of an action potential within a neuron but wrote nothing about signal transmission between two neurons.

### Neuron-to-Muscle Cell Communication

- Students often stated that “the muscle contracts”, and context made clear that they were referring to the entire muscle (e.g., gastrocnemius) rather than an individual muscle fiber.
- Rarely did students describe events associated with the sliding filament theory.
- In the papers that had a reflex arc as an example, students usually referred to the arc as a single entity and concluded with a statement of how one pulls one’s hand away from a hot object as a response. Rarely did students isolate two individual cells (neuron–neuron or neuron–muscle fiber) and explain events in terms of cell-to-cell communication.

### Endocrine Communication

- Students often were unable to link an endocrine gland correctly to a hormone from that gland, although they were more often able to link a hormone correctly to its appropriate effects.
- Understanding of the action of steroid vs. nonsteroid hormones was lacking.

## Question 3 Scoring Guidelines

Question 3 is a three-part question that begins with a stem describing a classification system based on a taxonomic category called the domain. This classification system is different from the Five-Kingdom system that is currently taught to most biology students. Students were asked to **describe** how this new classification scheme is different from the five-kingdom system; **describe and explain** how three kinds of evidence were used to develop the new scheme; and finally, **describe** four characteristics of a universal ancestor. To receive full credit, students had to answer all three parts, but points were distributed in the following way:

- Section I - 4 points
- Section II - 6 points
- Section III - 4 points

A maximum of 9 points could be earned for Sections I and II or Sections II and III. Students could receive a score of 10 only by answering all three sections of the question.

Section I could be answered by students who knew the five-kingdom system, and could interpret the diagram provided in the question. Section II required students to know something about Eubacteria, Archaeobacteria, and Eukaryotes. Section III required students to understand that a universal ancestor probably had characteristics common to all three domains. Students were awarded only 1 point in Section III for a *list* of characteristics of the universal ancestor; full credit required a description of the characteristics. Since Section II asked how evidence was used to develop the taxonomic scheme, not for comparison with the five-kingdom system of classification, any differences among the domains were accepted. Also, Section II asked for three kinds of evidence. As indicated in the directions printed on the back of the pink booklet, only the first three characteristics that a student described were graded, even though many students wrote on more than three.

**For full credit, a student must receive at least 1 point from each section.**

### Section I

*Maximum of 4 points from this section*

For Section I, the guidelines included a list of six possible conclusions (each worth 1 point) about relationships among organisms that could be drawn from the classification scheme presented. These conclusions showed this classification scheme to be different from the five-kingdom system. Another point could have been earned by listing the five kingdoms from the earlier classification system.

- (1) Not all prokaryotes are closely related (not monophyletic).
- (1) Prokaryotes split early in the history of living things (not all in one lineage).
- (1) Archaea are more closely related to Eukarya than to Bacteria.
- (1) Eukarya are not directly related to Eubacteria.
- (1) There was a common ancestor for all extant organisms (monophyletic).
- (1) Eukaryotes are more closely related to each other (than Prokaryotes are to each other)
- (1) Correct description of the five-kingdom system.

### Section II

*Maximum of 6 points, 3 points from the first three descriptions of evidence mentioned and 3 from the explanations. The explanations must differentiate between at least two of the groups.*

Part II asked for three descriptions of kinds of evidence that were used to develop the new classification scheme. The students then had to go further and explain how the evidence was used. It was expected that in this part differences among the three domains would be described. Each difference mentioned was worth 1 point. The explanations should indicate which group had which characteristic. In order to get the explanation point, students had to compare at least two of the three groups. The guidelines for this section list 28 possible different kinds of evidence that the students might describe and explain in order to get points on this section.



Descriptions	Explanations		
	Eukaryotes	Archaea	Eubacteria
Differences			
Habitat — mostly extreme (halophilic, thermophilic, acidic)	–	+	–
Reproduction	Mitosis/meiosis	Binary fission	Binary fission
Multicellularity exists	+	–	–
Nucleus	+	–	–
Membrane-bound organelles	+	–	–
Microtubules/ microfilaments	+	–	–
Cell walls with peptidoglycan	–	–	+
Chromosomes: Shape Number Histones present	Linear More than one +	Circular One +	Circular One –
Ribosomes: Size Base sequence of rRNA	Large Similar	Small Similar	Small Unique
Structure of tRNA	Similar	Unique	Similar
RNA polymerase	Multiple types	Multiple types	Single type
Introns	Present	Some	None
Operon organization of genes	–	+	–
Initiator amino acid in protein formation	Methionine	Methionine	Formyl-methionine
Phospholipids: Bonds Hydrocarbon structure		Ether Branched	Ester Unbranched
Can be pathogens	+	–	–
Response to antibiotics such as streptomycin or chloramphenicol	–	–	+
Response to diphtheria toxins	+	–	–
Metabolism Can be methanogens Enzymatic make-up differs Enzyme location differs Photosynthetic pigments differ	–	+	–
Differences in gene sequences of DNA	Must correctly describe what the difference is.		
Differences in whole genome sequences	Must correctly describe what the difference is.		

### Section III

**Maximum of 4 points for this section.** Described characteristics can earn 1 point each OR 1 point may be earned for a list of the first four correct characteristics. The question asked for descriptions, but it was decided that just listing the four characteristics correctly without describing them would earn 1 point.

#### Characteristic (possible explanations)

- (1) Small (surface to volume ratio, no internal transport system)
- (1) Unicellular (all functions self-contained)
- (1) Prokaryote (no membrane-bound organelles).
- (1) Had cell membrane (containment, protection, semipermeable)
- (1) Had cell membrane made of a phospholipid bilayer (barrier).
- (1) Had cytoplasm (different from external environment)
- (1) Had DNA for the genetic material (**or** nucleic acid **or** RNA)
- (1) Had mRNA for information transfer (common to all organisms)
- (1) Had tRNA to carry amino acids and/or aminoacylsynthetase (common to all organisms)
- (1) Had ability to reproduce (asexual)
- (1) Had ability to mutate, adapt, or evolve through natural selection
- (1) Had ability to make proteins or had ribosomes on which proteins could be constructed
- (1) Had metabolism: carbon-based or organic; Energy transformations, ATP as energy molecule
- (1) Had enzymes for amino acid, nucleotide, and coenzyme synthesis as well as enzymes for glycolysis and the Krebs cycle (common to all organisms)
- (1) Heterotrophic/autotrophic\* with explanation
- (1) Anaerobic/aerobic with explanation
- (1) Aquatic with explanation

Because Part II asked for six pieces of information (“**describe** 3 . . . and **explain**. . .”), and Part III asked for a description of four characteristics, a maximum of 4 points were attainable for parts I and III and 6 points were attainable for part II. It was necessary to answer each part of the question in order to get full credit; a maximum of 9 points were awarded for either parts I and II or II and III.

\*not photosynthetic

### Sample Student Responses for Free-Response Question 3

#### Essay 1 (6 points)

Scientists have never been able to agree on a single method of classification. It used to be believed that animals were not related to bacteria in any way. They had evolved from separate forms of life and were not related. The <sup>generally-</sup>accepted system with 5 categories had kingdoms Animal, plant, protist, fungi, and bacteria, showing a sort of evolutionary tree. The new classification shown here is a broader one in the eukaryotic branch. ~~The~~ Eukaryotes have a "true nucleus" that is membrane bound, while <sup>or nucleus</sup> prokaryotes do not have a membrane bound nucleus. The Eukaryote branch on this diagram includes plants, animals, fungi, and most protists that were originally separated in the kingdom system of classification. By looking at the chart, it appears ~~is if~~ if eukaryotes were related to archaeobacteria at a closer time than the eubacteria. It also concludes that archaeobacteria should be closer in structure to eukaryotes than to the other prokaryotic group, eubacteria. Archaeobacteria are not commonly understood, as they have the most resemblance to eukaryotic organisms of the 2 bacterial families. They have chloroplasts like plants and some protists and even resemble protists physically in structure, with ~~a~~ false feet, pseudopods, and in shape.

Four characteristics of the common ancestor were: that it was organic, probably used chemicals as a means of obtaining energy rather than photosynthesis or heterotrophism, it was a producer, and was very small in size, microscopic even, with basic simple structure and DNA composition.

### Commentary on Essay 1

The student earned 3 points from Part I: 1 for correctly explaining the five kingdoms, 1 for explaining that the eukaryotes are more closely related to each other than was implied in the five-kingdom system, and 1 for explaining that Archaeobacteria and Eukaryotes are more closely related than either is to the Bacteria.

Imbedded in the student's answer for Part I are 2 earned points for Part II. The student explained that one piece of evidence that was used to separate the domains was the presence or absence of a membrane-bound nucleus and that it is present in eukaryotes, but not in prokaryotes.

The student earned 1 point for Part III. Even though he/she did not *describe* the characteristics of the universal ancestor, he/she did list four possible characteristics.

## Essay 2 (8 points)

- The system of domains is different in that it does not group Bacteria and Archaea together as the five Kingdom system did. It is also different in that the evolutionary lines appear to be different. The archaea were thought to be ancestors of the bacteria domain but from this diagram they are along the lines of the Eukaryotes while the bacteria have a separate line. The Kingdom classification is concerned more with the division of Eukaryotes than the division of types of cells.
- The ~~most~~ evidence used to create the taxonomic scheme can come from the actual structure of the organisms. Mitochondria in Eukaryotes is thought to have been descended from the archaeobacteria called Purple sulfur bacteria and thus they are grouped together. ~~Photosynthesis~~ Bacteria did not use chemosynthesis and utilized other methods such as photosynthesis ~~to~~ <sup>to</sup> obtain energy. In To separate Eukaryotes from archaeobacteria and eubacteria, the chromosome structure was used as well. The ~~chromosomes~~ <sup>DNA</sup> in eubacteria and archaeobacteria ~~is~~ <sup>is</sup> circular and bound to the cell membrane. The bacteria ~~only~~ both only contain one <sup>circle of DNA</sup> chromosome. The Eukaryotes contain several chromosomes worth of DNA. The method of replication is thus different as well, the two domains of bacteria ~~can~~ replicate by binary fission while eukaryotic cells go through mitosis to replicate.

- The universal ancestor must have had a cell membrane which includes a phospholipid bilayer. This provides for exchange of chemicals with the environment and protects the organism.
- This universal ancestor must have used DNA as ~~a~~ ~~method of~~ ~~transfer~~ genetic information. The DNA codes for proteins which are needed to in the function of an organism.
- It must have had some method of acquiring energy with ATP. The ATP fuels the other processes in the cell.
- It must have had some method of protein synthesis with ribosomes and ~~RNA~~ ~~is~~ so that the bacteria because proteins are required for metabolic functions.

#### Commentary on Essay 2

This student was able to interpret the cladogram and also had the knowledge necessary to explain it. In Part I the student earned 2 points, one by explaining that the prokaryotes (group Bacteria and Archaeobacteria) are not monophyletic, and 2 by showing that the Archaeobacteria are more closely related to the Eukaryotes than to the Eubacteria.

In Part II the student earned credit for saying that there are differences in chromosome number in the bacteria and Eukaryotes, then explaining that the eubacteria and archaeobacteria have a single chromosome while the eukaryotes have several chromosomes. Unfortunately, the student began the paragraph with an attempt to give two pieces of evidence that were not correct, so the reader, who assigns points only to the *first three* items mentioned, was not able to give points to the evidence of reproduction differences the student mentioned at the end of the paragraph.

In Part III the student earned the maximum number of points possible (4) and even had further correct information. Two points were earned for (1) describing the cell membrane and its function, (2) stating that the cell membrane is a phospholipid bilayer and further explaining the functions. Two more points were earned for explaining that (1) DNA would be the genetic material and the (2) DNA coded for proteins.

## Essay 3 (10 points)

This classification scheme differs in that the old one lumped Archeobacteria and eubacteria into a single kingdom, labeled ~~Monera~~. These bacteria were considered simply prokaryotes.

Prok Kingdom      eukaryotic Kingdoms—all others.

↓  
monera (Archaebacteria and eubacteria)

The conclusions are different for the following reasons. Placing the archaebacteria as a branch off the eukaryotic domain implies that it is more closely related to the eukaryotic stock than eubacterial stock. Secondly, placing this divergence in a higher taxon implies that the Kingdom grouping of bacteria is inadequate. Not only are archaebacteria and eubacteria not close enough to be in the same Kingdom, they are in different domains. Thirdly, this system acknowledges that eukaryotes are an inclusive taxon and it places them not as simply offshoots of bacteria, but as a divergent strain from a common ancestor with archaebacteria.

The first evidence that archaebacteria are not to be grouped with eubacteria is that they have a different membrane and cell wall composition. They lack layers of peptidoglycan that eubacteria have. This characteristic is closer to eukaryotes. Secondly, Archaebacteria are



accustomed to extreme conditions that eubacteria are not. They can be extreme halophiles, living in extreme salt, or thermococci that live in extremely hot or acidic environments, and they can live as methanogens in the guts of animals, neither of which a eubacteria is capable of. Thirdly eukaryotes are divided from the other 2 domains because they have different ribosomes, an endomembrane system, different methods of gene regulation and protein production and different cell wall make up if any.

A characteristic of the universal ancestor would be the presence of ribosomes to produce proteins. Second would be the presence of DNA as genetic material for protein codes. Third would be the existence of a phospholipid bilayer as a plasma membrane. and fourth would be glycolysis as a means of extracting energy from glucose into ATP.

### Commentary on Essay 3

This is a superior paper. In Part I, the student clearly explained that the diagram separated the Archaeobacteria and Eubacteria into two domains and put the Archaeobacteria in a closer relationship to the Eukaryotes. Furthermore, he/she mentioned that the Eukaryotes are inclusive. Three points were earned.

In Part II, the student earned 2 points by citing differences in cell wall composition as evidence for separation of the Eubacteria from other domains. The student further explained that the difference in cell wall composition is due to the presence of peptidoglycan in the Eubacteria and its absence in the other domains. The second 2 points were earned by his/her discussion of habitat differences between the Archaea and Eukaryotes and Bacteria. Finally 2 points were earned by the discussion of metabolism differences in Archaeobacteria from Eukaryotes and Bacteria demonstrated by the production of methane by some Archaeobacteria.

In Part III, the student gave an excellent description of four characteristics of the universal ancestor, all of which were correct. The student could have earned 4 points. The whole question has a maximum of 10 points which the student more than earned!

### Common Errors and Misconceptions

Many students seemed:

- to be unfamiliar with the term "domain" (it is not prominent in the textbooks) even though it was not necessary to have known about domains to earn a good score on the question;
- to be unable to read the cladogram;
- not to understand the major differences between Eukarya and Bacteria;
- confused about cyanobacteria and protists.



## Question 4 Scoring Guidelines

The stem of question 4 describes three criteria of hereditary material (precise copying, stable but able to change, complex enough to determine phenotype). Students are asked to explain how DNA meets these criteria. After selecting one of the criteria, students have to describe the evidence from experiments that supports knowledge that DNA is the hereditary material.

The standards for the first part of the question focusing on how DNA meets the three criteria listed in the question were fairly straightforward, with many opportunities to garner points. The second part of the question was more complicated in that the question asked more than just describing an experiment that showed that DNA was the genetic material. The question asks students to link their chosen experiment to one of the criteria listed in the stem. For this question, the first part requires more information than the second does, so the point values were split 8 to 2 between the two parts.

**Note: Part A can earn a maximum of 8 points. Part B can earn a maximum of 2 points.**

A. Explain how DNA meets each of the three criteria stated above [8 points maximum]

1. Molecular Properties for Precise COPYING [3 points maximum]

- Template concept (semi-conservative replication)
- Molecular structure (e.g., complementary base pairing; A:T,C:G; purine-pyrimidine pairing; antiparallel)
- DNA polymerase function in copying
- Separation concept
- Elaboration of replication (e.g., specific roles of other replication enzymes, proper sequence of steps)

### How students could earn points in this section:

Points were awarded in this section for correctly linking structure or other molecular properties of DNA to the copying mechanism. One point could also be awarded for a description of the copying process without an accompanying explanation linking the steps to molecular properties. A point could also be earned for explaining the role of DNA polymerase.

2. Molecular Properties that make it STABLE but ABLE to change [3 points maximum]

### Stable

- Energetically favorable arrangement; stable because of shape of molecule (e.g., double helix; bases in the interior of the helix)
- Energetically favorable arrangement; stable because of bonding (e.g., multiple H bonds; phosphodiester bonds)
- Silent errors (e.g., “junk” DNA; introns; redundancy of the genetic code)
- Able to be repaired (e.g., proofreading)

### Able

- Description of a mutation (e.g., substitution; deletion; insertion; inversion; translocation)
- Crossing over (e.g., during meiosis)
- Base changes (e.g., depurination; deamination; tautomerism)
- Gene rearrangements (e.g., antibody genes in stem cells; transposons)
- Sensitive to mutagens (e.g., UV; X-ray)
- Restriction enzyme recognition sequences

**Stable or Able** (with justification)

- Methylation
- Telomeres protect ends

**How students could earn points in this section:**

In this section students could earn points for discussing the properties that make DNA stable and for discussing the points that make DNA able to be changed. The student could earn the maximum by addressing either or both aspects of this criterion. No points were awarded for general description of the molecule unless the student specifically linked the description to the ability to remain stable or be able to change. (Students often described the molecule, e.g., *double helix*, *H bonds between the bases*, without demonstrating any understanding that these properties contribute to stability and/or changeability.) For the same reason, a point for the mutation concept was not awarded unless the student described a type of mutation, showing how mutation changes the molecule, e.g., *during replication the molecule can change because it is possible for it to experience a base substitution*, rather than *DNA can change by mutation*. The latter seems to say DNA can change by changing. Two properties included in the standards could arguably provide either stability or changeability. Either explanation was acceptable with justification.

3. Molecular Properties that make it COMPLEX enough to determine PHENOTYPE [3 points maximum]

- Colinearity of gene and protein (i.e., base sequence determines aa sequence)
- Infinite base sequence combinations lead to protein variety
- Variable numbers of base pairs per gene lead to different sizes of polypeptides
- Proteins are responsible for phenotype
- Description of transcription and translation
- Chromosome structure as it relates to function (e.g., supercoiling; chromosome or gene inactivation; interaction with histones; etc.)

**How students could earn points in this section:**

Points were awarded for describing the properties of the molecule that make it complex enough to determine phenotype. One point could be awarded for a description of transcription and translation without an accompanying explanation linking the steps to molecular properties.

B. Select one of the criteria stated above and describe experimental evidence used to determine that DNA is the hereditary material [2 points maximum]

- Identification of experiment with valid link to any one of the criteria [1 point maximum]:
  - 1) precise copying
  - 2) stable but able to change
  - 3) complex enough to determine phenotype
  - 4) DNA is the hereditary material
- May include but need not be limited to experiments that show:
  - DNA can transform bacteria
  - viral DNA can reprogram cells
  - equivalence of A:T and C:G
  - double helix structure, (e.g., x-ray crystallography)
  - replication is semiconservative

- hereditary enzyme deficiency disorders have genetic links
- DNA codes for protein
- changes in DNA quantities during the cell cycle (mitosis/meiosis)
- chromosome markers linked to disorders
- measurement of mutation rates
- changes in DNA (biotechnology)
- Description of EVIDENCE [1 point maximum]  
Evidence provided in the context of an experiment

**How students could earn points in this section:**

One point was awarded for correctly identifying an experiment that provided evidence for the criterion chosen by the student. If more than one criterion was selected, the reader scored the first one chosen. The readers treated "*that DNA is the hereditary material*" as a fourth criterion. Therefore, even though only three criteria were actually enumerated in the question, the students could choose an experiment that provided evidence for this implied fourth criterion. While not every experiment cited was familiar to the readers, every experiment cited was judged according to whether it could reasonably provide the evidence described. The second point was awarded for describing the evidence in the context of an experiment.

## Sample Student Responses for Free-Response Question 4

### Essay 1 (10 points)

DNA replicates itself using semiconservative replication. This means that each parent strand of DNA will serve as the template for forming a new DNA molecule, resulting in daughter molecules that are  $\frac{1}{2}$  old DNA and  $\frac{1}{2}$  new. The DNA molecule is split down the middle by helicase, which breaks the bonds holding the complementary nucleotides together. Helicase functions in a 3' to 5' direction, while the next step, synthesis, occurs in a 5' to 3' direction, with 3' and 5' denoting the ends of the DNA molecule. A new strand is synthesized by DNA polymerase, which catalyzes the adding of new nucleotides to each half of the DNA molecule. Thus, each daughter DNA molecule is identical to its parent, ~~because of the presence of the parent~~

The DNA molecule is held together in the middle by hydrogen bonds between the 2 strands, and nucleotides are attached to one another lengthwise down the molecule by phosphodiester bonds. Both of these bonds, plus the coiling of the molecule, contribute to its stability. However, variation is possible due to mutations in the DNA. Mutations may be caused by a number of sources, but they all include the changing of the sequence of nucleotides. ~~Not~~ Nucleotides may be inserted into the chain, deleted, or translocated. Each of these mutations corresponds to a change in the structure of the protein that the gene codes for, which may or may not have serious effects.

DNA consists of 4 nucleotides - adenine, guanine, cytosine, + thymine. Adenine + guanine are purines, and have complementary structures to cytosine + thymine, which are pyrimidines (A pairs with T, + C pairs with G) These four nucleotides, arranged in various sequences along a molecule of DNA are responsible for the incredible diversity of proteins that may be produced. Nucleotides code for proteins in triplets, or codons. Each amino acid corresponds to several

## Sample Student Responses for FRQ 4

different codons. (64 codons are possible, and 20 amino acids exist, with 2 codons signalling for "stop") The phenotype of an organism is a result of the variations in the proteins produced in this way.

Messelson & Stahl performed an experiment to prove Watson & Crick's theory of semiconservative replication of the DNA molecule. They used a centrifuge to separate DNA from bacteria. The DNA formed a band visible in the tube. When the bacteria were grown in a medium containing heavy nitrogen isotope ( $^{15}\text{N}$ ), the band was in a different place. When they allowed the bacteria to grow in the medium long enough for 1 generation of replication, the band formed was between the 2 light & heavy bands, suggesting that it consisted of  $\frac{1}{2}$  light &  $\frac{1}{2}$  heavy DNA. One more replication <sup>in a  $^{14}\text{N}$  medium</sup> would result in only light & medium bands, showing that half of the strands were all new DNA, while the other half were hybrid light & heavy. This proved that each time, half of the DNA served as a template for replication of a new half of the molecule.

### Commentary on Essay 1

This paper earned a 10 and was very concisely written. On part A(1) the student earned the maximum 3 points; one for describing the template concept, one for describing the DNA separation concept, and one for describing the role of DNA polymerase in copying. The student actually addressed all 5 points listed in the standards. On part A(2) the maximum 3 points were again awarded, one for explaining that the shape of the molecule contributes to its stability, one for explaining that hydrogen bonds contribute to the stability, and one for explaining that insertions, deletions, and translocations change the DNA molecule. Two points were awarded for part A(3), one for explaining that many base sequences are possible and one for explaining that proteins are responsible for phenotype. In part B both points were earned, one for correctly linking an experiment to the "copy" criterion and one for describing the essential design of, and the experimental evidence derived from, the Meselson and Stahl experiment.

## Essay 2 (8 points)

DNA, a double helix shaped molecule composed of alternating base pair sequences, nucleotides consisting of a base, phosphate backbone, and simple sugar, and linked in the middle by hydrogen bonds (as proposed by Watson and Crick), can easily copy itself, is fairly stable, and very complex. By first ~~unzipping~~ unzipping itself with the aid of DNA polymerase, DNA is able to replicate having the complementary base pairs of adenine, guanine, thymine and cytosine detach and being joined by other loose DNA strands on the leading 3' and lagging 5' ends. This semi-conservative replication is efficient, quick, and easy. DNA ligase, polymerase, and helicase enzymes all aid in the unzipping, re-binding, and finishing of the replicated strands.

DNA is stable, having all the base pairs bound by the hydrogen bonds and phosphate backbone. It is neither acidic nor basic, isn't radioactive, can be combined with other DNA strands from other sources (such as linking human DNA with bacteria strands during recombination). However, it is susceptible to change as the genetic <sup>information</sup> ~~sequence~~ housed in the base pairs can be changed as mutations change the sequence of the bases. Deletions can remove a base from a replicating strand, insertions may add an extra base, inversions will reverse a sequence, point mutations, frameshift will change the sequence, and many more. These may have no effect, but most often do as the change in bases causes a change in what amino acid, enzyme, or

otherwise, is produced. Thus, it is stable but can be changed.

Finally, it is very complex as each facet of an organisms' genotype is within the system of bases of the DNA. These bases are then specifically assorted in ways numbering billions upon billions which, depending on that assortment, codes for every aspect of the phenotype (physical expression of the genotype - genetic makeup of an organism). A simple shift, addition, deletion or change of one or more of these bases causes a change in the genotype, and thus, a change in the phenotype.

The complex system of bases and their bonding and harboring of information was determined by Watson and Crick whose theories and postulations on the double helix shape of the DNA molecule deduced such information. And, the experiments of Meselson and Stahl deduced the semi-conservative reproductive replicative nature of DNA when they observed a replicating DNA in a liquid medium and studied the effects.

### Commentary on Essay 2

This answer earned 8 points. In part A(1) the student earned the maximum 3 points, one for describing the DNA separation concept, one for describing complementarity in DNA structure, and one for describing the template concept. In part A(2) the maximum 3 points were earned, one for explaining that hydrogen bonds contribute to stability, one for explaining that the molecule can be changed by recombining DNA through biotechnology (restriction enzyme point), and one for explaining how deletions can change DNA. For part A(3) the student earned one point for linking the large assortment of base arrangements to phenotype. In part B the student earned the "identifying the experiment" point. The student chose the "DNA is the genetic material" criterion (first choice) and got credit for identifying Watson and Crick's DNA modeling. The experimental design and evidence were not adequately described to earn the second point for either of the experiments cited.



### Essay 3 (6 points)

DNA meets each of the criteria because it can copy itself through the process of DNA replication in which each half of the DNA strand serves as a template for a new complementary strand (semiconservative). It also includes structures such as DNA ligase and helicase which check and fix DNA errors (along with DNA polymerase). The arrangement of hydrogen bonds, phosphates, and nitrogenous bases contribute to its stability. And the varying sequences of the bases allow DNA to be complex enough to determine an organism's phenotype. The order of the bases dictate which amino-acids are produced therefore determining which phenotype is expressed.

To determine that DNA was in fact the hereditary material used to determine the organism's phenotype, a few scientists used bacteriophages incorporated with  $^{32}\text{P}$  and  $^{27}\text{S}$ . Mixing a bacteria culture with the bacteriophages, the scientists were able to determine whether DNA was the hereditary material by tracing the movement of of the isotopes ( $^{32}\text{P}$  and  $^{27}\text{S}$ ). The  $^{32}\text{P}$  was ~~at~~ incorporated into the bacteriophage's DNA while the  $^{32}\text{S}$  combined with another cellular organelle. From the new colonies, produced by the infected bacteria, only  $^{32}\text{P}$  was present indicating that the DNA from the "parent" bacteria colony was replicated and produced in the "daughter" bacteria colony. Therefore, DNA had to be the genetic material.

#### Commentary on Essay 3

Although the essay includes several errors, it still conveys a general sense of understanding the subject. In part A(1) the student earned 1 point for understanding the template concept but did not provide any specific details to earn the other points. In part A(2) the student earned 2 points for describing both the hydrogen bonding property and proofreading to explain stability. In part A(3) the student earned 1 point for linking base arrangement to phenotype. For part B the student chose the "DNA is the genetic material" criterion. He/she earned 1 point for identifying an appropriate experiment and 1 point for describing the evidence in the context of the experiment.



## Common Errors and Misconceptions

Students know many facts about DNA structure, replication, transcription, and translation. Some of the things we have learned from the responses are that many students:

- know that the two chains of the double helix are complementary but don't understand why that is significant
- know that there are hydrogen bonds between the complementary base pairs but don't understand why that is significant
- understand the relationship of mutation to DNA structure
- know a lot of technical vocabulary terms but are very confused about how the details they have learned fit together coherently
- know structure, but are generally weak on process, or why structure is important
- do not understand what constitutes experimental evidence
- do not distinguish between evidence and conclusions drawn from evidence
- understand the relationship between genes and proteins

- do not understand the relationship between DNA, RNA, nucleotides, amino acids, and proteins
- do not understand that gene expression *is* phenotype
- do not know the difference between replication and transcription

## What Can Teachers Do to Improve Performance in Specific Problem Areas?

Separate the teaching of replication and protein synthesis and teach them in the context of the biological processes in which they are involved. For example:

- Teach DNA structure when teaching about the structure of other macromolecules.
- Teach about replication when teaching about the cell cycle.
- Teach about protein synthesis when teaching about Mendel's laws and transmission genetics.

In addition, make every effort to teach students to ask and answer questions about why and how. Stress the process of science by discussing why and how we know what we know rather than describing what we know.

# Chapter IV Statistical Information

- Table 4.1 — Section II Scores
- How AP Grades Are Determined
- Table 4.2 — Scoring Worksheet
- Table 4.3 — Grade Distributions
- Table 4.4 — Section I Scores and AP Grades
- College Comparability Studies
- Reminders for All Grade Report Recipients
- Reporting AP Grades
- Purpose of AP Grades

**Table 4.1 — Section II Scores**

These are the score distributions for the total group of candidates on each free-response question from the 1999 AP Biology Exam.

Score	Question 1		Question 2		Question 3		Question 4	
	Number of Students	% At Score	Number of Students	% At Score	Number of Students	% At Score	Number of Students	% At Score
10	97	0.1	2017	2.5	1239	1.5	363	0.4
9	381	0.5	1612	2.0	1117	1.4	896	1.1
8	1349	1.7	2529	3.1	1821	2.2	2121	2.6
7	3801	4.7	3198	3.9	2758	3.4	3690	4.5
6	8189	10.0	4159	5.1	4075	5.0	5646	6.9
5	14316	17.6	5081	6.2	5766	7.1	8399	10.3
4	19308	23.7	6497	8.0	7760	9.5	10601	13.0
3	16155	19.8	8107	9.9	9969	12.2	11777	14.5
2	9231	11.3	9183	11.3	12479	15.3	11650	14.3
1	4434	5.4	7978	9.8	15610	19.2	11592	14.2
0	2526	3.1	26365	32.4	11901	14.6	12164	14.9
*NR	1707	2.1	4768	5.9	6999	8.6	2595	3.2
Total Candidates	81494		81494		81494		81494	
Mean	3.82		2.51		2.59		2.98	
Standard Deviation	183		2.80		2.45		2.34	
Mean as % of Maximum Score	38		25		26		30	

\*NR — No response. Student gave either no response or a response not on the topic.

## How AP Grades Are Determined

Students could have received 0 to 119 points in Section I and 0 to 60 points in Section II of this exam. However, these scores are not released to the student, school, or college. Instead, these raw scores are converted to grades on an AP 5-point scale, and it is these grades that are reported. This conversion involves a number of steps, which are detailed on the Scoring Worksheet on the facing page:

1. **The multiple-choice score is calculated.** To adjust for random guessing, a fraction of the number of wrong answers is subtracted from the number of right answers. This fraction is  $1/4$  for five-choice questions (as on the Biology Exam), so that the expected score from random guessing will be zero.
2. **The free-response score is calculated.** When the free-response section includes two or more parts, those parts are weighted according to the value assigned to them by the Development Committee. This allows the Committee to place more importance on certain skills to correspond to their emphasis in the corresponding college curriculum.
3. **A composite score is calculated.** Weighting also comes into play when looking at the multiple-choice section in comparison to the free-response section. In consultation with experts from the College Board and ETS, the Biology Committee decided that Section I should contribute 60% and Section II should contribute 40% to the total score. The maximum composite score was 150. The

Scoring Worksheet on the facing page details the process of converting section scores to composite scores for this exam.

4. **AP grades are calculated.** The Chief Faculty Consultant sets the four cut points that divide the composite scores into groups. A variety of information is available to help the CFC determine the score ranges into which the exam grades should fall:
  - Distributions of scores on each portion of the multiple-choice and free-response sections of the exam, along with totals for each section and the composite score total, are provided.
  - With these tables and special statistical tables presenting grade distributions from previous years, the CFC can compare the exam at hand to results of other years.
  - For each composite score, a roster summarizes student performance on all sections of the exam.
  - Finally, on the basis of professional judgment regarding the quality of performance represented by the achieved scores, the CFC determines the candidates' final AP grades.

See Table 4.3 for the 1999 AP Biology Exam grade distributions.

If you're interested in more detailed information about this process, please see the "Technical Corner" of our website: [www.collegeboard.org/ap](http://www.collegeboard.org/ap). There you'll also find information about how the AP Exams are developed, how validity and reliability studies are conducted, and other nuts-and-bolts data on all AP subjects.

Table 4.2 — Scoring Worksheet

**Section I: Multiple Choice**

$$\left[ \frac{\text{Number correct (out of 119)} - (1/4 \times \text{Number wrong})}{\text{Multiple-Choice Score}} \right] \times .7563 = \text{Weighted Section I Score}$$

**Section II: Free Response**

Question 1  $\frac{\text{_____ (out of 10)}}{\text{_____}} \times 1.500 = \text{_____}$

Question 2  $\frac{\text{_____ (out of 10)}}{\text{_____}} \times 1.500 = \text{_____}$

Question 3  $\frac{\text{_____ (out of 10)}}{\text{_____}} \times 1.500 = \text{_____}$

Question 4  $\frac{\text{_____ (out of 10)}}{\text{_____}} \times 1.500 = \text{_____}$

Sum = \_\_\_\_\_

Weighted Section II Score

**Composite Score**

$$\begin{array}{ccc} \text{_____} & + & \text{_____} & = & \text{_____} \\ \text{Weighted Section I Score} & & \text{Weighted Section II Score} & & \text{Composite Score} \\ & & & & \text{(Round to nearest whole number.)} \end{array}$$

**AP Grade Conversion Chart  
Biology 1999**

Composite Score Range*	AP Grade
86-150	5
66-85	4
48-65	3
29-47	2
0-28	1

\*The candidates' scores are weighted according to formulas determined in advance each year by the Development Committee to yield raw composite scores; the Chief Faculty Consultant is responsible for converting composite scores to the 5-point AP scale.

**Table 4.3 — Grade Distributions**

More than 65% of the candidates earned an AP grade of 3 or higher.

	Examination Grade	Total Group Number of Students	Percent at Grade
Extremely well qualified	5	15,954	19.6
Well qualified	4	17,979	22.1
Qualified	3	19,147	23.5
Possibly qualified	2	17,766	21.8
No recommendation	1	10,638	13.1
Total Number of Students			81,494
Mean Grade			3.13
Standard Deviation			1.31

**Table 4.4 — Section I Scores and AP Grades**

This table gives the probabilities that a student would receive a particular grade on the 1999 AP Biology Exam given that student's particular score on the multiple-choice section.

Multiple-Choice	AP Grade					Total
	1	2	3	4	5	
80 to 119	0.0%	0.0%	0.0%	12.4%	87.5%	18.5%
63 to 79	0.0%	0.0%	13.1%	71.7%	15.2%	21.9%
46 to 62	0.0%	11.7%	71.6%	16.6%	0.1%	24.5%
29 to 45	6.9%	78.9%	14.1%	0.1%	0.0%	21.7%
0 to 28	86.3%	13.6%	0.0%	0.0%	0.0%	13.4%
Total	13.1%	21.8%	23.5%	22.1%	19.6%	100.0%

## College Comparability Studies

The Advanced Placement Program has conducted college grade comparability studies in all AP subjects. These studies have compared the performance of AP Exam candidates with that of college students in related courses who have taken the AP Exam at the end of their course. In general, AP cutpoints are selected so that the lowest AP 5 is equivalent to the average grade of A in college, the lowest AP 4 equivalent to the average B, and the lowest AP 3 equivalent to the average C (see figure below).

AP Grade	Average College Grade
5	A
4	B
3	C
2	D
1	

Other studies conducted by colleges and universities indicate that AP students generally receive higher grades in advanced courses than do the students who have taken the regular freshman-level courses at the institution. Each college is encouraged to undertake such studies in order to establish appropriate policy for the acceptance of AP grades. Data for these studies are readily available as large percentages of AP students successfully handle the associated course work. Some institutions have found that until these studies are undertaken, placing students into advanced classes but allowing them to transfer to a lower-level course if necessary, is a desirable educational strategy.

## Reminders for All Grade Report Recipients

AP Examinations are designed to provide accurate assessments of achievement. However, any examination

has limitations, especially when used for purposes other than those intended. Presented here are some suggestions for teachers to aid in the use and interpretation of AP grades.

- AP Examinations in different subjects are developed and evaluated independently of each other. They are linked only by common purpose, format, and method of reporting results. Therefore, comparisons should not be made between grades on different AP Examinations. An AP grade in one subject may not have the same meaning as the same AP grade in another subject, just as national and college standards vary from one discipline to another.
- AP grades are not exactly comparable to college course grades. However, the AP Program conducts research studies every few years in each AP subject to ensure that the AP grading standards are comparable to those used in colleges with similar courses.
- The confidentiality of candidate grade reports should be recognized and maintained. All individuals who have access to AP grades should be aware of the confidential nature of the grades and agree to maintain their security. In addition, school districts and states should not release data about high school performance without the school's permission.
- AP Examinations are not designed as instruments for teacher or school evaluation. A large number of factors influence AP Exam performance in a particular course or school in any given year. As a result, differences in AP Exam performance should be carefully studied before being attributed to the teacher or school.
- Where evaluation of AP students, teachers, or courses is desired, local evaluation models should be developed. An important aspect of any evaluation model is the use of an appropriate method of comparison or frame of reference to account for yearly changes in student composition and ability, as well as local differences in resources, educational methods, and socioeconomic factors.

- The “Report to AP Teachers,” sent to schools automatically when five or more students take a particular AP Exam, can be a useful diagnostic tool in reviewing course results. This report identifies areas of strength and weakness for the students in each AP course. This information may also provide teachers with guidance for course emphasis and student evaluation.
- Many factors can influence course results. AP Exam performance may be due to the degree of agreement between your course and the course defined in the relevant AP Course Description, use of different instructional methods, differences in emphasis or preparation on particular parts of the examination, differences in pre-AP curriculum, or differences in student background and preparation in comparison with the national group.

## Reporting AP Grades

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The results of AP Examinations are disseminated in several ways to candidates, their secondary schools, and the colleges they select.

- College and candidate grade reports contain a cumulative record of all grades earned by the candidate on AP Exams during the current or previous years. These reports are sent in early July. (School grade reports are sent shortly thereafter.)
- Group results for AP Examinations are available to AP teachers whenever five or more candidates at a school have taken a particular AP Exam. This

“Report to AP Teachers” provides useful information comparing local candidate performance with that of the total group of candidates taking an exam, as well as details on different subsections of the exam.

Several other reports produced by the AP Program provide summary information on AP Examinations.

- State and National Reports show the distribution of grades obtained on each AP Exam for all candidates and for subsets of candidates broken down by sex and by ethnic group.
- The Program also produces a one-page summary of AP grade distributions for all exams in a given year.

For information on any of the above, please call AP Services at (609) 771-7300 or contact them via e-mail at [apexams@ets.org](mailto:apexams@ets.org).

## Purpose of AP Grades

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AP grades are intended to allow participating colleges and universities to award college credit, advanced placement, or both to qualified students. In general, an AP grade of 3 or higher indicates sufficient mastery of course content to allow placement in the succeeding college course, or credit for and exemption from a college course comparable to the AP course. Credit and placement policies are determined by each college or university, however, and students should be urged to contact their colleges directly to ask for specific advanced placement policies in writing.



A number of AP publications, CD-ROMs, and videos are available to help students, parents, AP Coordinators, and high school and college faculty learn more about the AP Program and its courses and exams. To sort out those publications that may be of particular use to you, refer to the following key:

Students and Parents	SP
Teachers	T
AP Coordinators and Administrators	A
College Faculty	C

You can order many items online through the AP Aisle of the College Board Online store at <http://cbweb2.collegeboard.org/shopping/>. Alternatively, call AP Order Services at (609) 771-7243. American Express, VISA, and MasterCard are accepted for payment.

If you are mailing your order, send it to the Advanced Placement Program, Dept. E-05, P.O. Box 6670, Princeton, NJ 08541-6670. Payment must accompany all orders not on an institutional purchase order or credit card, and checks should be made payable to the College Board.

The College Board pays fourth-class book rate postage (or its equivalent) on all prepaid orders; you should allow between four and six weeks for delivery. Postage will be charged on all orders requiring billing and/or requesting a faster method of shipment.

Publications may be returned within 15 days of receipt if postage is prepaid and publications are in resalable condition and still in print. Unless otherwise specified, orders will be filled with the currently available edition; prices are subject to change without notice.

### **AP Bulletin for Students and Parents: Free** **SP**

This bulletin provides a general description of the AP Program, including policies and procedures for preparing to take the exams, and registering for the AP courses. It describes each AP Exam, lists the advantages of taking the exams, describes the grade and award options available to students, and includes the upcoming exam schedule.

### **Student Guides (available for Calculus, English, and U.S. History): \$12** **SP**

These are course and exam preparation manuals designed for high school students who are thinking about or taking a specific AP course. Each guide answers questions about the AP course and exam, suggests helpful study resources and test-taking strategies, provides sample test questions with answers, and discusses how the free-response questions are scored.

### **College and University Guide to the AP Program: \$10** **C, A**

This guide is intended to help college and university faculty and administrators understand the benefits of having a coherent, equitable AP policy. Topics included are validity of AP grades; developing and maintaining scoring standards; ensuring equivalent achievement; state legislation supporting AP; and quantitative profiles of AP students by each AP subject.

### **Course Descriptions: \$12** **SP, T, A, C**

Course Descriptions provide an outline of the AP course content, explain the kinds of skills students are expected to demonstrate in the corresponding introductory college-level course, and describe the AP Exam. They also provide sample multiple-choice questions with an answer key, as well as sample free-response questions. A set of Course Descriptions for all AP subjects is available for \$100. Course Descriptions are also available for downloading from the AP section of the College Board website (free of charge).

### **Five-Year Set of Free-Response Questions: \$5** **T**

This is our no-frills publication. Each booklet contains copies of all the free-response questions from the last five exams in its subject; nothing more, nothing less. Collectively, the questions represent a comprehensive sampling of the concepts assessed on the exam in recent years and will give teachers plenty of materials to use for essay-writing or problem-solving practice during the year. (If there have been any content changes to the exam in the past five years, it will be noted on the cover of the booklet.)



**Interpreting and Using AP Grades: Free** A, C, T

A booklet containing information on the development of scoring standards, the AP Reading, grade-setting procedures, and suggestions on how to interpret AP grades.

**Guide to the Advanced Placement Program: Free** A

Written for both administrators and AP Coordinators, this guide is divided into two sections. The first section provides general information about AP, such as how to organize an AP program at your high school, the kind of training and support that is available for AP teachers, and a look at the AP Exams and grades. The second section contains more specific details about testing procedures and policies and is intended for AP Coordinators.

**Released Exams: \$20**

**(\$30 for “double” subjects: Calculus, Latin, Physics)** T

About every four years, on a staggered schedule, the AP Program releases a complete copy (multiple-choice and free-response sections) of each exam.

*Packets of 10: \$30.* For each subject with a released exam, you can purchase a packet of 10 copies of that year’s exams (\$30) for use in your classroom (e.g., to simulate an AP exam administration).

**Secondary School Guide to the AP Program: \$10** A, T

This guide is a comprehensive consideration of the AP Program. It covers topics such as: developing or expanding an AP program; gaining faculty, administration, and community support; AP grade reports, their use and interpretation; AP Scholar Awards; receiving college credit for AP; AP teacher training resources; descriptions of successful AP programs in nine schools around the country; and “Voices of Experience,” a collection of ideas and tips from AP teachers and administrators.

**Teacher’s Guides: \$12** T

Whether you’re about to teach an AP course for the first time, or you’ve done it for years but would like to get some fresh ideas for your classroom, the Teacher’s Guide can be your adviser. It contains syllabi developed by high school teachers currently teaching the AP course and college faculty who teach the equivalent course at their institution. Along with detailed course outlines and innovative teaching tips, you’ll also find extensive lists of recommended teaching resources.

**AP Vertical Team Guides** T, A

An AP Vertical Team (APVT) is made up of teachers from different grade levels who work together to develop and implement a sequential curriculum in a given discipline. The team’s goal is to help students acquire the skills necessary for success in AP. In order to help teachers and administrators who are interested in establishing an APVT at their school, the College Board has published three guides: *AP Vertical Teams in Science, Social Studies, Foreign Language, Studio Art, and Music Theory: An Introduction* (\$12); *A Guide for Advanced Placement English Vertical Teams* (\$10); and *Advanced Placement Program Mathematics Vertical Teams Toolkit* (\$35). A discussion of the English Vertical Teams guide, and the APVT concept, is also available on a 15-minute VHS videotape (\$10).

**College Board Online (CBO)** SP, T, A, C

You can supplement your AP course and preparation for the exam with abundant advice and resources from our AP web pages ([www.collegeboard.org/ap](http://www.collegeboard.org/ap)).

**EssayPrep™****SP, T**

EssayPrep is also available through CBO. Students can select an essay topic, type a response, and get an evaluation from an experienced reader. The service is offered for the free-response portions of the AP Biology, English Language and Composition, English Literature and Composition, and U.S. History Exams. The fee is \$15 per response for each evaluation. SAT II: Writing topics are also offered for a fee of \$10. Multiple evaluations can be purchased at a 10-20% discount. You can access EssayPrep from the CBO home page, or from the individual AP subject pages.

**The College Handbook with College Explorer®****CD-ROM: \$25.95****SP, T, A, C**

Includes brief outlines of AP placement and credit policies at two- and four-year colleges across the country. Notes number of freshmen granted placement and/or credit for AP in the prior year.

**APCDs®: \$49 (home version),****\$450 (multi-network site license)****SP, T**

These CD-ROMs are currently available for U.S. History, English Literature, English Language, and European History; the Calculus AB and Spanish Language versions will follow in spring 2000. They each include actual AP Exams, interactive tutorials, and other features including exam descriptions, answers to frequently asked questions, study skill suggestions, and test-taking strategies. There is also a listing of resources for further study and a planner for students to schedule and organize their study time.

**Videoconference Tapes: \$15****SP, A, C, T**

AP conducts live, interactive videoconferences for various subjects, enabling AP teachers and students to talk directly with the Development Committees that design the AP Exams. Tapes of these events are available in VHS format and are approximately 90 minutes long.

**AP Pathway to Success (video available****in English and Spanish): \$15****SP, T, A, C**

This 25-minute-long video takes a look at the AP Program through the eyes of people who know AP: students, parents, teachers, and college admissions staff. They answer such questions as “Why Do It?”, “Who teaches AP Courses?”, and “Is AP For You?”. College students discuss the advantages they gained through taking AP, such as academic self-confidence, writing skills, and course credit. AP teachers explain what the challenge of teaching AP courses means to them and their school, and admissions staff explain how they view students who have stretched themselves by taking AP Exams. There is also a discussion of the impact that an AP program has on an entire school and its community, and a look at resources available to help AP teachers, such as regional workshops, teacher conferences, and summer institutes.

**What’s in a Grade? (video): \$15****T, C**

AP Exams are composed of multiple-choice questions (scored by computer), and free-response questions that are scored by qualified professors and teachers. This video presents a behind-the-scenes look at the scoring process featuring footage shot on location at the 1992 AP Reading at Clemson University and other Reading sites. Using the AP European History Exam as a basis, the video documents the scoring process. It shows AP faculty consultants in action as they engage in scholarly debate to define precise scoring standards, then train others to recognize and apply those standards. Footage of other subjects, interviews with AP faculty consultants, and explanatory graphics round out the video.

# AP Biology

## 1998-1999 Development Committee in AP Biology

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