The College Board

AP® ADVANCED PLACEMENT PROGRAM®

Course Description

PHYSICS

Physics B, Physics C

PH

MAY 2004, MAY 2005

The College Board is a national nonprofit membership association whose mission is to prepare, inspire, and connect students to college and opportunity. Founded in 1900, the association is composed of more than 4,300 schools, colleges, universities, and other educational organizations. Each year, the College Board serves over three million students and their parents, 22,000 high schools, and 3,500 colleges through major programs and services in college admissions, guidance, assessment, financial aid, enrollment, and teaching and learning. Among its best-known programs are the SAT®, the PSAT/NMSQT®, and the Advanced Placement Program® (AP®). The College Board is committed to the principles of equity and excellence, and that commitment is embodied in all of its programs, services, activities, and concerns.

For further information, visit www.collegeboard.com

The College Board and the Advanced Placement Program encourage teachers, AP Coordinators, and school administrators to make equitable access a guiding principle for their AP programs. The College Board is committed to the principle that all students deserve an opportunity to participate in rigorous and academically challenging courses and programs. All students who are willing to accept the challenge of a rigorous academic curriculum should be considered for admission to AP courses. The Board encourages the elimination of barriers that restrict access to AP courses for students from ethnic, racial, and socioeconomic groups that have been traditionally underrepresented in the AP Program. Schools should make every effort to ensure that their AP classes reflect the diversity of their student population.

For more information about equity and access in principle and practice, contact the National Office in New York.

For the College Board's online home for AP professionals, visit AP Central at apcentral.collegeboard.com.

Dear Colleagues:

In 2002, more than one million high school students benefited from the opportunity of participating in AP® courses, and nearly 940,000 of them then took the challenging AP Exams. These students felt the power of learning come alive in the classroom, and many earned college credit and placement while still in high school. Behind these students were talented, hardworking teachers who collectively are the heart and soul of the AP Program.

The College Board is committed to supporting the work of AP teachers. This AP Course Description outlines the content and goals of the course, while still allowing teachers the flexibility to develop their own lesson plans and syllabi, and to bring their individual creativity to the AP classroom. To support teacher efforts, a Teacher's Guide is available for each AP subject. Moreover, AP workshops and Summer Institutes held around the globe provide stimulating professional development for more than 60,000 teachers each year. The College Board Fellows stipends provide funds to support many teachers' attendance at these Institutes. Stipends are now also available to middle school and high school teachers using Pre-AP® strategies.

Teachers and administrators can also visit AP Central™, the College Board's online home for AP professionals at apcentral.collegeboard.com. Here, teachers have access to a growing set of resources, information, and tools, from textbook reviews and lesson plans to electronic discussion groups (EDGs) and the most up-to-date exam information. I invite all teachers, particularly those who are new to AP, to take advantage of these resources.

As we look to the future, the College Board's goal is to broaden access to AP while maintaining high academic standards. Reaching this goal will require a lot of hard work. We encourage you to connect students to college and opportunity by not only providing them with the challenges and rewards of rigorous academic programs like AP, but also by preparing them in the years leading up to AP.

Sincerely,

Gaston Caperton
President
The College Board

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Welcome to the AP® Program

The Advanced Placement Program® (AP®) is a collaborative effort between motivated students, dedicated teachers, and committed high schools, colleges, and universities. Since its inception in 1955, the Program has allowed millions of students to take college-level courses and exams, and to earn college credit or placement while still in high school.

Most colleges and universities in the U.S., as well as colleges and universities in 21 other countries, have an AP policy granting incoming students credit, placement, or both on the basis of their AP Exam grades. Many of these institutions grant up to a full year of college credit (sophomore standing) to students who earn a sufficient number of qualifying AP grades.

Each year, an increasing number of parents, students, teachers, high schools, and colleges and universities turn to AP as a model of educational excellence.

More information about the AP Program is available at the back of this Course Description and at AP Central™, the College Board's online home for AP professionals (apcentral.collegeboard.com). Students can find more information at the AP student site (www.collegeboard.com/apstudents).

AP Courses

Thirty-four AP courses in a wide variety of subject areas are currently available. Developed by a committee of college faculty and AP teachers, each AP course covers the breadth of information, skills, and assignments found in the corresponding college course. See page 2 for a list of the AP courses and exams that are currently offered.

AP Exams

Each AP course has a corresponding exam that participating schools worldwide administer in May. Except for Studio Art, which is a portfolio assessment, AP Exams contain multiple-choice questions and a free-response section (either essay or problem-solving).

AP Exams represent the culmination of AP courses, and are thus an integral part of the Program. As a result, many schools foster the expectation that students who enroll in an AP course will go on to take the corresponding AP Exam. Because the College Board is committed to providing homeschooled students and students whose schools do not offer AP access to the AP Exams, it does not require students to take an AP course prior to taking an AP Exam.

AP Courses and Exams

Art
Art History
Studio Art (Drawing Portfolio)
Studio Art (2-D Design Portfolio)
Studio Art (3-D Design Portfolio)

Biology

Calculus
Calculus AB
Calculus BC

Chemistry

Computer Science
Computer Science A
Computer Science AB

Economics
Macroeconomics
Microeconomics

English
English Language and Composition
English Literature and Composition

Environmental Science

French
French Language
French Literature

German Language

Government and Politics
Comparative Government and Politics
United States Government and Politics

History
European History
United States History
World History

Human Geography

Latin
Latin Literature
Latin: Vergil

Music Theory

Physics
Physics B
Physics C: Electricity and Magnetism
Physics C: Mechanics

Psychology

Spanish
Spanish Language
Spanish Literature

Statistics

Introduction to AP Physics

Shaded text indicates important new information about this subject.

What We Are About

A Message from the Development Committee

The AP Physics Development Committee recognizes that curriculum, course content, and assessment of scholastic achievement play complementary roles in shaping education at all levels. The committee believes that assessment should support and encourage the following broad instructional goals:

1. *Physics knowledge* — Basic knowledge of the discipline of physics, including phenomenology, theories and techniques, concepts, and generalizing principles.
2. *Problem solving* — Ability to ask physical questions and to obtain solutions to physical questions by use of qualitative and quantitative reasoning, and by experimental investigation.
3. *Student attributes* — Fostering of important student attributes, including appreciation of the physical world and the discipline of physics, curiosity, creativity, and reasoned skepticism.
4. *Connections* — Understanding connections of physics to other disciplines and to societal issues.

The first three of these goals are appropriate for the AP and introductory-level college physics courses which should, in addition, provide a background for the attainment of the fourth goal.

The AP Physics Examinations have always emphasized achievement of the first two goals. Over the years, the definitions of basic knowledge of the discipline and problem solving have evolved. The AP Physics courses have reflected changes in college courses, consistent with our primary charge. At present we are increasing our emphasis on physical intuition, experimental investigation, and creativity. We are including more open-ended questions in order to assess students' understanding of physical concepts. We are structuring questions that stress the use of mathematics to illuminate the physical situation rather than to show manipulative abilities.

The committee is dedicated to developing examinations that can be graded fairly and consistently and that are free of ethnic, gender, economic, or other bias. We operate under practical constraints of testing methods, allotted time, and large numbers of students at widely spread geographical locations. In spite of these constraints, the committee strives to design examinations that promote excellent and appropriate instruction in physics.

The Courses

Two AP Examinations in Physics, identified as Physics B and Physics C, are offered. These examinations are designed to test student achievement in the Physics B and Physics C courses described in this booklet. These courses are intended to be representative of courses commonly offered in colleges and universities, but they do not necessarily correspond precisely to courses at any particular institution. The aim of an AP secondary school course in physics should be to develop the students' abilities to do the following:

1. Read, understand, and interpret physical information — verbal, mathematical, and graphical.
2. Describe and explain the sequence of steps in the analysis of a particular physical phenomenon or problem; that is,
   a. describe the idealized model to be used in the analysis, including simplifying assumptions where necessary,
   b. state the concepts or definitions that are applicable,
   c. specify relevant limitations on applications of these principles,
   d. carry out and describe the steps of the analysis, verbally or mathematically, and
   e. interpret the results or conclusions, including discussion of particular cases of special interest.
3. Use basic mathematical reasoning — arithmetic, algebraic, geometric, trigonometric, or calculus, where appropriate — in a physical situation or problem.
4. Perform experiments and interpret the results of observations, including making an assessment of experimental uncertainties.

In the achievement of these goals, concentration on basic principles of physics and their applications through careful and selective treatment of well-chosen areas is more important than superficial and encyclopedic coverage of many detailed topics. Within the general framework outlined on pages 16-19, teachers may exercise some freedom in the choice of topics.

In the AP Physics Examinations, an attempt is made through the use of multiple-choice and free-response questions to determine how well these goals have been achieved by the student either in a conventional course or through independent study. The level of the student's achievement is assigned an AP grade of 1 to 5, and many colleges use this grade alone as the basis for placement and credit decisions.

Introductory college physics courses typically fall into one of three categories, designated as A, B, and C in the following discussion.

Category A includes courses in which major concepts of physics are covered without as much mathematical rigor as in more formal courses, such as Physics B and Physics C, which are described below. The emphasis in *Category A* courses is on developing a qualitative conceptual understanding of general principles and models and on the nature of scientific inquiry. Some courses may also view physics primarily from a cultural or historical perspective. *Category A* courses are generally intended for students not majoring in a science-related field. The level of mathematical sophistication usually includes some algebra and may extend to simple trigonometry, but rarely beyond. These courses vary widely in content and approach, and at present there is no AP course or exam in this category. A high school version of a *Category A* course that concentrates on conceptual development and that provides an enriching laboratory experience may be taken by students in the 9th or 10th grade and should provide the first course in physics that prepares them for a more mathematically rigorous AP Physics B or C course.

Category B courses build on the conceptual understanding attained in a first course in physics, such as the *Category A* course described above. They provide a systematic development of the main principles of physics, emphasizing problem solving as well as continuing to develop a deep understanding of physics concepts. It is assumed that the student is familiar with algebra and trigonometry; calculus is seldom used, although some theoretical developments may use basic concepts of calculus. In most colleges, this is a one-year terminal course including a laboratory component and is not the usual preparation for more advanced physics and engineering courses. However, *Category B* courses often provide a foundation in physics for students in the life sciences, premedicine, and some applied sciences, as well as other fields not directly related to science. The AP Physics B course is intended to be equivalent to such courses.

Category C courses also build on the conceptual understanding attained in a first course in physics, such as the *Category A* course described above. They normally form the college sequence that serves as the foundation in physics for students majoring in the physical sciences or engineering. The sequence is parallel to or preceded by mathematics courses that include calculus. Methods of calculus are used wherever appropriate in formulating physical principles and in applying them to physical problems. The sequence is more intensive and analytic than in *Category B* courses. Strong emphasis is placed on solving a variety of challenging problems, some requiring calculus, as well as continuing to develop a deep understanding of physics concepts. A *Category C* sequence may be a very intensive one-year course in college, but often will extend over one and one-half to two years, and a laboratory component is also included. The AP Physics C course is intended to be equivalent to part of a *Category C* sequence and covers two major areas; mechanics, and electricity and magnetism, with equal emphasis on these two areas.

In certain colleges and universities, other types of unusually high-level introductory courses are taken by a few selected students. Selection of students for these courses is often based on results of AP Examinations, other college admission information, or a college-administered examination. The AP Examinations are not designed to grant credit or exemption for such high-level courses but may facilitate admission to them.

Course Selection

It is important for those teaching and advising AP students to consider the relation of AP courses to a student's college plans. In some circumstances it is advantageous to take the AP Physics B course. The student may be interested in studying physics as a basis for more advanced work in the life sciences, medicine, geology, and related areas, or as a component in a non-science college program that has science requirements. Credit or advanced placement for the Physics B course provides the student with an opportunity either to have an accelerated college program or to meet a basic science requirement; in either case the student's college program may be enriched. Access to an intensive physics sequence for physics or science majors is another opportunity that may be available.

For students planning to specialize in a physical science or in engineering, most colleges require an introductory physics sequence of which the C course is the first part. Since a previous or concurrent course in calculus is often required of students taking the C course, students who expect advanced placement or credit for Physics C should attempt an AP course in calculus as well; otherwise, placement in the next-in-sequence physics course may be delayed or even denied. Either of the AP Calculus courses, Calculus AB or Calculus BC, should provide an acceptable basis for students preparing to major in the physical sciences or engineering, but Calculus BC is recommended. Therefore, if such students must choose between AP Physics or AP Calculus while in high school, they should probably choose calculus.

There are two separate AP Physics Examinations, Physics B and Physics C. Students take one examination or the other. Both examinations contain multiple-choice and free-response questions. The Physics B examination is for students who have taken a Physics B course or who have mastered the material of this course through independent study.
The Physics B examination covers topics in mechanics, electricity and

magnetism, fluid mechanics and thermal physics, waves and optics, and atomic and nuclear physics; a single examination grade is reported. Similarly, the Physics C examination corresponds to the Physics C course. One part of the Physics C examination covers mechanics; the other part covers electricity and magnetism. Students are permitted to take either or both parts of this examination, and separate grades are reported for the two subject areas to provide greater flexibility in planning AP courses and making advanced placement decisions.

Further descriptions of the two kinds of AP Physics courses and their corresponding examinations in terms of topics, level, mathematical rigor, and typical textbooks are presented in the pages that follow. Information about organizing and conducting AP Physics courses, of interest to both beginning and experienced AP teachers, may be found in the *Teacher's Guide — AP Physics.* This publication includes practical advice from successful AP teachers and detailed sets of objectives for both examinations. *The 1998 AP Physics B & Physics C Released Exams* booklet contains the entire 1998 Physics B and Physics C examinations, the solutions and grading standards for the free-response sections of these examinations, sample student responses, as well as statistical data on student performance. For information about ordering these publications and others, see the back of this booklet. Additional useful information may be found at AP Central™ (apcentral.collegeboard.com).

Instructional Approaches

It is strongly recommended that both Physics B and Physics C be taught as second-year physics courses. A first-year physics course aimed at developing a thorough understanding of important physical principles and that permits students to explore concepts in the laboratory provides a richer experience in the process of science and better prepares them for the more analytical approaches taken in AP courses.

However, secondary school programs for the achievement of AP course goals can take other forms as well, and the imaginative teacher can design approaches that best fit the needs of his or her students. In some schools, AP Physics has been taught successfully as a very intensive first-year course; but in this case there may not be enough time to cover the material in sufficient depth to reinforce the students' conceptual understanding or to provide adequate laboratory experiences. This approach can work for highly motivated, able students but is not generally recommended. Independent study or other first-year physics courses supplemented with extra work for individual motivated students are also possibilities that have been successfully implemented.

In a school that uses block scheduling, it is strongly recommended that AP Physics be scheduled to extend over an entire year. A one-year AP course should not be taught in one semester, as this length of time is insufficient for students to properly assimilate and understand the important concepts of physics that are covered in the syllabus.

More detailed descriptions about alternate approaches can be found in the *Teacher's Guide – Physics*. Whichever approach is taken, the nature of the AP course requires teachers to spend time on the extra preparation needed for both class and laboratory. AP teachers should have a teaching load that is adjusted accordingly.

Laboratory Experience

Laboratory experience must be part of the education of AP Physics students and should be included in all AP Physics courses just as it is in introductory college physics courses. Students should be able to:

- design experiments,
- observe and measure real phenomena,
- organize, display, and critically analyze data,
- determine uncertainties in measurement,
- draw inferences from observations and data, and
- communicate results, including suggested ways to improve experiments and proposed questions for further study.

In textbooks and problems, most attention is paid to idealized situations: friction is assumed to be constant or absent; meters read true values; heat insulators are perfect; gases follow the ideal gas equation. In the laboratory, the validity of these assumptions can be questioned because there the student meets nature as it is rather than in idealized form.

Laboratory experience should also help students understand the topics being considered. Students need to be proficient in problem solving and in the application of fundamental principles to a wide variety of situations. Problem-solving ability can be fostered by investigations that are somewhat nonspecific. Such investigations are often more interesting and valuable than "cookbook" experiments that merely investigate a well-established relationship, and which can take important time away from the rest of the course. Thus it is often valuable to ask students to write informally about what they have done, observed, and concluded, as well as it is for them to keep well-organized laboratory notebooks.

Some questions or parts of questions on the AP Physics Examinations may distinguish between students who have had laboratory experience and those who have not. In addition, understanding gained in the laboratory may improve the students' test performance overall.

Laboratory programs in both college courses and AP courses differ widely, and there is no clear evidence that any one approach is necessarily best. This diversity of approaches should be encouraging to the high school teacher of an AP course. The success of a given program depends strongly on the interests and enthusiasm of the teacher and on the general ability and motivation of the students involved.

Although programs differ, the AP Physics Development Committee has made some recommendations in regard to school resources and scheduling. Students in AP Physics should have adequate and timely access to computers that are connected to the Internet and its many online resources. Students should also have access to computers with appropriate sensing devices and software for use in gathering, graphing, and analyzing laboratory data, and writing reports. Although using computers in this way is a useful activity and is encouraged, some initial experience with gathering, graphing, and manipulating data by hand is also important for students to be able to attain a better feel for the physical realities involved in the experiments. And it should be emphasized that simulating an experiment on a computer cannot adequately replace the actual "hands-on" experience of doing an experiment.

Flexible or modular scheduling is best in order to meet the time requirements identified in the course outline. Some schools are able to assign daily double periods so that laboratory and quantitative problem-solving skills may be fully developed. At the very least, a weekly extended or double laboratory period is needed. *It is not advisible to attempt to complete high-quality AP laboratory work within standard 45- to 50-minute periods.*

If AP Physics is taught as a second-year physics course, following a first-year course with a strong laboratory component, then somewhat less time might be devoted to labs in the AP course. However, the AP labs should build on and extend the lab experiences of the first-year course. Students should be encouraged to save evidence of their first-year lab work, such as their lab reports or a lab notebook, as well as similar evidence of the lab work in their AP course. The important criterion is that students completing an AP Physics course must have had laboratory experiences that are roughly equivalent to those in a comparable introductory college course.

Therefore, school administrations should realize the implications, both in cost and time, of incorporating serious laboratories into their program. An AP course is a college course, and the equipment and time allotted to laboratories should be similar to that in a college course.

To provide guidance for the development of the AP courses and exams, the AP Program undertakes periodic surveys of introductory college courses. A 1998 survey of both non-calculus and calculus-based introductory physics courses obtained some information about the laboratory programs in these courses. The survey revealed that nearly all the courses of either type included a laboratory, and that on average from two to three hours per week are devoted to laboratory activities. Secondary schools may have difficulty scheduling this much weekly time for lab. However, the college academic year typically contains fewer weeks than the secondary school year, so AP teachers may be able to schedule a few more lab periods during the year than can the colleges. Also, some college faculty have reported that some lab time may be occasionally used for other purposes as well. Nevertheless, in order for AP students to have sufficient time for lab, at least one double period per week is recommended for all AP Physics courses.

In response to a survey question about whether separate credit is given for lab, the percent of the colleges indicating that credit is given separately was 39% for non-calculus courses and 34% for calculus-based courses. For these separate lab courses the mean number of credit hours awarded was just slightly higher than one, and the mean number of credit hours awarded for the rest of the course was 3.4 for the non-calculus courses and 3.7 for the calculus-based courses. For the courses for which lab credit was not awarded separately, the lab component contributed on average about 18% of final course grade for both non-calculus and calculus-based courses. Thus it appears that when all the introductory courses are considered together, about 20% of the total course credit awarded can be attributed to lab performance.

One question in the survey asked the colleges for the percent of the laboratory activities that can be classified depending on levels of student involvement. The categories were: (1) prescribed or "cookbook," (2) limited investigations with some direction provided, and (3) open investigations with little or no direction provided. Most colleges (93% for non-calculus courses, 90% for calculus-based courses) reported that they do labs in the first category and of these colleges the mean percentage of their labs in this category were 82% for non-calculus courses and 75% for calculus-based courses. However, many colleges (55% for non-calculus courses, 70% for calculus-based courses) also reported doing labs in the second category, with the mean percentages being 40% for both types of courses. Far fewer colleges (12% for non-calculus courses, 20% for calculus-based courses) reported doing labs in the third category with the mean percentages being about 20-22% for both types of courses. While many college professors believe that labs in the latter two categories do have more value to students, they report often being limited in their ability to institute them by large class sizes and other factors. In this respect, AP teachers often have an advantage in being able to offer more open-ended labs to their students.

Another question asked the colleges to indicate which of a number of assessment techniques or instruments are used in assessing laboratory performance or determining laboratory grades. They were told to check all that apply. The percent of colleges indicating use of each type of assessment are shown below:

	Non-calculus courses (%)	Calculus-based courses (%)
Observation of lab performance	51	51
Lab practical exam	26	24
Written tests designed specifically for lab	29	32
Lab-related questions on regular written lecture tests	17	27
Lab reports	93	99
Lab notebooks	25	43
Lab portfolios	1	0
Other	17	13
(most common comment was pre-lab quizzes or assignments)		

Finally, the survey asked the colleges to check which of a number of skills were assessed if they attempted to assess laboratory skills with written test questions. They were again told to check all that apply. The percent of colleges indicating each type of skill are shown below:

	Non-calculus courses (%)	Calculus-based courses (%)
Design of experiments	48	29
Analysis of data	88	73
Analysis of errors	61	62
Evaluation of experiments and suggestions for future investigations	21	18
Other	18	27

A more detailed laboratory guide is scheduled for summer 2002, and will be posted on AP Central. This guide contains descriptions of a number of experiments that typify the type and level of skills that should be developed by AP students in conducting laboratory investigation. The experiments are not mandatory; they can be modified or similar experiments substituted as long as they assist the student in developing these skills. Each edition of the Teacher's Guide also provides additional suggestions for the laboratory. It mentions specific experiments that other AP teachers have tried and liked, and it lists publications and other sources of information that may provide additional ideas for possible low-cost experiments. The guide may be helpful to experienced AP teachers as well as to those just beginning to teach courses in AP Physics.

Documenting Laboratory Experience

The laboratory is important for both AP and college students. Students who have had laboratory experience in high school will be in a better position to validate their AP courses as equivalent to the corresponding college courses and to undertake the laboratory work in more advanced courses with greater confidence. Most college placement policies assume that students have had laboratory experience, and students should be prepared to show evidence of their laboratory work in case the college asks for it. Such experience can be documented by keeping a lab notebook or a portfolio of lab reports. Presenting evidence of *adequate college-level* laboratory experience to the colleges they attend can be very useful to students as an adjunct to their AP grades if they desire credit for or exemption from an introductory college course that includes a laboratory. Although colleges can expect that most entering AP students have been exposed to many of the same laboratory experiments performed by their own introductory students, individual consultation with students is often used to help determine the nature of their laboratory experience.

Physics B

The Physics B course includes topics in both classical and modern physics. A knowledge of algebra and basic trigonometry is required for the course; the basic ideas of calculus may be introduced in connection with physical concepts, such as acceleration and work. Understanding of the basic principles involved and the ability to apply these principles in the solution of problems should be the major goals of the course.

The following textbooks are commonly used in colleges and typify the level of the B course. However, the inclusion of a text in this list does not constitute endorsement by the College Board, ETS, or the AP Physics Development Committee.

Cutnell, John D. and Kenneth W. Johnson, *Physic*s, 6th ed. New York, John Wiley & Sons, 2003.

Giancoli, Douglas C., *Physics: Principles with Application*s, 5th ed. Upper Saddle River, NJ, Prentice Hall, 1998.

Hecht, Eugene, *Physics: Algebra/Trigonometr*y, 3rd ed. Pacific Grove, CA, Brooks/Cole Publishing, 2003.

Jones, Edwin R. and Richard L. Childers, *Contemporary College Physic*s, 3rd ed. Columbus, OH, McGraw Hill, 2001 update.

Sears, Francis W., Mark W. Zemansky, and Hugh D. Young, *College Physic*s, 7th ed. Boston, MA, Addison Wesley, 1991.

Serway, Raymond A. and Jerry S. Faughn, *College Physic*s, 6th ed. Pacific Grove, CA, Brooks/Cole Publishing, 2003.

Wilson, Jerry D. and Anthony J. Buffa, *College Physic*s, 5th ed. Upper Saddle River, NJ, Prentice Hall, 2003.

Although these texts are commonly used, the list is not exhaustive. The Teacher's Guide includes some additional suggestions for other texts, supplementary books, and other materials.

The Physics B course seeks to be representative of topics covered in similar college courses, as determined by periodic surveys. Accordingly, goals have been set to the percentages on pages 16–19 for coverage of five general areas: Newtonian mechanics, fluid mechanics and thermal physics, electricity and magnetism, waves and optics, and atomic and nuclear physics.

Beginning in 2003, the subtopic "Specific and latent heat (including calorimetry)" will be deleted from the topics covered by the B course.

Many colleges and universities include additional topics in their survey courses. Some AP teachers may wish to add supplementary material to a Physics B course. Many teachers have found that a good time to do this is later in the year, after the AP Examinations have been given.

Physics C

In the typical C course, roughly one-half year is devoted to mechanics. Use of calculus in problem solving and in derivations is expected to increase as the course progresses.

In the second half-year of the C course, the primary emphasis is on classical electricity and magnetism. Calculus is used freely in formulating principles and in solving problems.

The following textbooks are commonly used in colleges and typify the level of the C course. However, the inclusion of a text in this list does not constitute endorsement by the College Board, ETS, or the AP Physics Development Committee.

Fishbane, Paul M., Stephen Gasiorowicz, and Stephen T. Thornton, *Physics for Scientists and Engineer*s, 2nd ed. Upper Saddle River, NJ, Prentice Hall, 1996.

Giancoli, Douglas C., *Physics for Scientists and Engineers*, 3rd ed. Upper Saddle River, NJ, Prentice Hall, 2000.

Halliday, David, Robert Resnick, and Jearl Walker, *Fundamentals of Physic*s, 6th ed. Enhanced Problems Version. New York, John Wiley, 2002.

Halliday, David, Robert Resnick, and Kenneth Krane, *Physics*, *Parts I and II*, 5th ed. New York, John Wiley, 2001.

Serway, Raymond A. and Robert Beichner, *Physics for Scientists and Engineer*s, 5th ed. Pacific Grove, CA, Brooks/Cole Publishing, 2000.

Serway, Raymond A. and John W. Jewett, Jr., *Principles of Physics*, 3rd ed. Pacific Grove, CA, Brooks/Cole Publishing, 2002.

Tipler, Paul A. and Gene P. Mosca, *Physics for Scientists and Engineer*s, 5th ed. New York, W.H. Freeman, 2003.

Wolfson, Richard, and Jay M. Pasachoff, *Physics for Scientists and Engineer*s, 3rd ed. Boston, MA, Addison Wesley, 1999.

Young, Hugh D. and Roger A. Freedman, *Sears and Zemansky's University Physic*s, 10th ed. Boston, MA, Addison Wesley, 2000.

Although these texts are commonly used, the list is not exhaustive. The Teacher's Guide includes some additional suggestions for other texts, supplementary books, and other materials.

Most colleges and universities include in a C course additional topics such as wave motion, kinetic theory and thermodynamics, optics, alternating current circuits, or special relativity. Although wave motion, optics, and kinetic theory and thermodynamics are usually the most commonly included, there is little uniformity among such offerings, and these topics are not included in the C examination. The Development Committee recommends that supplementary material be added to a Physics C course when it is possible to do so. Many teachers have found that a good time to do this is late in the year, after the AP Examinations have been given.

Comparison of Topics in Physics B and Physics C

To serve as an aid for devising AP Physics courses and to more clearly identify the specifics of the examinations, a detailed topical structure has been developed that relies heavily on information obtained in college surveys. The general areas of physics are subdivided into major categories on pages 16-19, and for each category the percentage goals for each examination are given. These goals should serve only as a guide and should not be construed as reflecting the proportion of course time that should be devoted to each category.

Also for each major category, some important subtopics are listed. The checkmarks indicate the subtopics that may be covered in each examination. Questions for the examination will come from these subtopics, but not all of the subtopics will necessarily be included in every examination, just as they are not necessarily included in every AP or college course.

It should be noted that although fewer topics are covered in Physics C than in Physics B, they are covered in greater depth and with greater analytical and mathematical sophistication, including calculus applications.

Content Outline for Physics B and Physics C

Content Area	Percentage Goals for Examinations: Physics B	Percentage Goals for Examinations: Physics C
I. Newtonian Mechanics	35%	50%
A. Kinematics (including vectors, vector algebra, components of vectors, coordinate systems, displacement, velocity, and acceleration)	7%	9%
1. Motion in one dimension	√	√
2. Motion in two dimensions, including projectile motion	√	√
B. Newton's laws of motion (including friction and centripetal force)	9%	10%
1. Static equilibrium (first law)	√	√
2. Dynamics of a single particle (second law)	√	√
3. Systems of two or more bodies (third law)	√	√
C. Work, energy, power	5%	7%
1. Work and work-energy theorem	√	√
2. Conservative forces and potential energy	√	√
3. Conservation of energy	√	√
4. Power	√	√
D. Systems of particles, linear momentum	4%	6%
1. Center of mass		√
2. Impulse and momentum	√	√
3. Conservation of linear momentum, collisions	√	√

Content Area	Percentage Goals for Examinations: Physics B	Physics C
E. Circular motion and rotation	4%	9%
1. Uniform circular motion	√	√
2. Angular momentum and its conservation		
a. Point particles		√
b. Extended bodies, including rotational inertia		√
3. Torque and rotational statics	√	√
4. Rotational kinematics and dynamics		√
F. Oscillations and gravitation	6%	9%
1. Simple harmonic motion (dynamics and energy relationships)	√	√
2. Mass on a spring	√	√
3. Pendulum and other oscillations	√	√
4. Newton's law of gravity	√	√
5. Orbits of planets and satellites		
a. Circular	√	√
b. General		√
II. Fluid Mechanics and Thermal Physics	15%	
A. Fluid Mechanics	6%	
1. Hydrostatic pressure	√	
2. Buoyancy	√	
3. Fluid flow continuity	√	
4. Bernoulli's equation	√	
B. Temperature and heat	2%	
1. Mechanical equivalent of heat	√	
2. Heat transfer and thermal expansion	√	
C. Kinetic theory and thermodynamics	7%	
1. Ideal gases		
a. Kinetic model	√	
b. Ideal gas law	√	
2. Laws of thermodynamics		
a. First law (including processes on pV diagrams)	√	
b. Second law (including heat engines)	√	

Content Area	*Percentage Goals for Examinations* Physics B	Physics C
III. Electricity and Magnetism	25%	50%
A. Electrostatics	5%	15%
1. Charge, field, and potential	√	√
2. Coulomb's law and field and potential of point charges	√	√
3. Fields and potentials of other charge distributions		
a. Planar	√	√
b. Spherical symmetry		√
c. Cylindrical symmetry		√
4. Gauss's law		√
B. Conductors, capacitors, dielectrics	4%	7%
1. Electrostatics with conductors	√	√
2. Capacitors		
a. Parallel plate	√	√
b. Spherical and cylindrical		√
3. Dielectrics		√
C. Electric circuits	7%	10%
1. Current, resistance, power	√	√
2. Steady-state direct current circuits with batteries and resistors only	√	√
3. Capacitors in circuits		
a. Steady state	√	√
b. Transients in RC circuits		√
D. Magnetostatics	4%	10%
1. Forces on moving charges in magnetic fields	√	√
2. Forces on current-carrying wires in magnetic fields	√	√
3. Fields of long current-carrying wires	√	√
4. Biot-Savart and Ampere's law		√
E. Electromagnetism	5%	8%
1. Electromagnetic induction (including Faraday's law and Lenz's law)	√	√
2. Inductance (including LR and LC circuits)		√
3. Maxwell's equations		√

Content Area	Percentage Goals for Examinations: Physics B	Percentage Goals for Examinations: Physics C
IV. Waves and Optics	15%	
A. Wave motion (including sound)	5%	
1. Properties of traveling waves	√	
2. Properties of standing waves	√	
3. Doppler effect	√	
4. Superposition	√	
B. Physical optics	5%	
1. Interference and diffraction	√	
2. Dispersion of light and the electromagnetic spectrum	√	
C. Geometric optics	5%	
1. Reflection and refraction	√	
2. Mirrors	√	
3. Lenses	√	
V. Atomic and Nuclear Physics	10%	
A. Atomic physics and quantum effects	7%	
1. Photons and the photoelectric effect	√	
2. Atomic energy levels	√	
3. Wave-particle duality	√	
B. Nuclear physics	3%	
1. Nuclear reactions (including conservation of mass number and charge)	√	
2. Mass-energy equivalence	√	

Laboratory and experimental situations: Each examination will include one or more questions or parts of questions posed in a laboratory or experimental setting. These questions are classified according to the content area that provides the setting for the situation, and each content area may include such questions. These questions generally assess some understanding of content as well as experimental skills, as described on the following pages.

Miscellaneous: Each examination may include occasional questions that overlap several major topical areas, or questions on miscellaneous topics such as identification of vectors and scalars, vector mathematics, graphs of functions, history of physics, or contemporary topics in physics.

The Examinations

The AP Physics B Examination is three hours long, divided equally between a 70-question multiple-choice section and a free-response section. The two sections are weighted equally, and a single grade is reported for the B Examination.

The free-response section will normally contain from 6 to 8 questions. Typical examples of its format are 6 questions, each taking about 15 minutes, or 4 questions of about 15 minutes each and 3 shorter questions of about 10 minutes each. However, future examinations might include a combination of questions of other lengths.

The AP Physics C Examination consists of two parts, each one and one-half hours long. One part covers mechanics, the other part, electricity and magnetism. A student may take either or both parts, and a separate grade is reported for each. In addition, the time for each part is divided equally between a 35-question multiple-choice section and a free-response section; the two sections are weighted equally in the determination of each grade. The usual format for each free-response section has been three questions, each taking about 15 minutes. However, future examinations might include a larger number of shorter questions.

The percentages of each examination devoted to each major category are specified in the preceding pages. Departures from these percentages in the free-response section in any given year are compensated for in the multiple-choice section so that the overall topic distribution for the entire examination is achieved as closely as possible, although it may not be reached exactly.

Some questions, particularly in the free-response sections, may involve topics from two or more major categories. For example, a question may utilize a setting involving principles from electricity and magnetism or atomic and nuclear physics, but parts of the question may also involve the application of principles of mechanics to this setting, either alone or in combination with the principles from electricity and magnetism or atomic and nuclear physics. Such a question would not be classified uniquely according to any particular topic, but would receive partial classifications by topics in proportion to the principles needed to arrive at the answers.

On both examinations the multiple-choice section emphasizes the breadth of the students' knowledge and understanding of the basic principles of physics; the free-response section emphasizes the application of these principles in greater depth in solving more extended problems. In general, questions may ask students to:

- determine directions of vectors or paths of particles;
- draw or interpret diagrams;

- interpret or express physical relationships in graphical form;
- account for observed phenomena;
- interpret experimental data, including their limitations and uncertainties;
- construct and use conceptual models and explain their limitations;
- explain steps taken to arrive at a result or to predict future physical behavior;
- manipulate equations that describe physical relationships;
- obtain reasonable estimates; or
- solve problems that require the determination of physical quantities in either numerical or symbolic form and that may require the application of single or multiple physical concepts.

Laboratory-related questions may ask students to:

- design experiments, including identifying equipment needed and describing how it is to be used, drawing diagrams or providing descriptions of experimental setups, or describing procedures to be used, including controls and measurements to be taken;
- analyze data, including displaying data in graphical or tabular form, fitting lines and curves to data points in graphs, performing calculations with data, or making extrapolations and interpolations from data;
- analyze errors, including identifying sources of errors and how they propagate, estimating magnitude and direction of errors, determining significant digits, or identifying ways to reduce errors;
- communicate results, including drawing inferences and conclusions from experimental data, suggesting ways to improve experiments, or proposing questions for further study.

The free-response section of each examination is printed in a separate booklet in which each part of a question is followed by a blank space for the student's solution. The same questions without the blank answer spaces are printed on green paper as an insert in the examination booklet. This green insert also contains a Table of Information and tables of commonly used equations. The Table of Information, which is also printed near the front of each multiple-choice section, includes numerical values of some physical constants and conversion factors, and states some conventions used in the examinations. The equation tables are described in greater detail in a later section. The green insert can be removed from the free-response answer booklet and used for reference when answering the free-response questions only.

The International System (SI) of units is used predominantly in both examinations. The use of rulers or straightedges is permitted on the free-response sections to facilitate the sketching of graphs or diagrams that might be required in these sections.

Since the complete examinations are intended to provide the maximum information about differences in students' achievement in physics, students may find these examinations more difficult than many classroom examinations. The best way for teachers to familiarize their students with the level of difficulty is to give them actual released examinations (both multiple-choice and free-response sections) from past administrations. Information about ordering publications is in the back of this booklet. Recent free-response sections can also be downloaded from AP Central along with scoring guidelines and some sample student responses.

The Free-Response Sections — Student Presentation

Students are expected to show their work in the spaces provided for the solution for each part of a free-response question. If they need more space, they should clearly indicate where the work is continued or they may lose credit for it. If students make a mistake, they may cross it out or erase it. Crossed-out work and any work shown on the green insert will not be graded, and credit may be lost for incorrect work that is not crossed out.

In grading the free-response sections, credit for the answers depends on the quality of the solutions and the explanations given, and partial solutions may receive partial credit, so students are advised to show all their work. Correct answers without supporting work may lose credit. This is especially true when students are asked specifically to justify their answer, in which case the graders are looking for some verbal or mathematical analysis that shows how the students arrived at their answer. Also, all final numerical answers should include appropriate units.

On the AP Physics Exams the words "justify," "explain," "calculate," "what is," "determine," and "derive" have precise meanings. Students should pay careful attention to these words in order to obtain maximum credit for their answers, and should avoid including irrelevant or extraneous material in their answers.

The ability to justify an answer in words shows understanding of the principles underlying physical phenomena in addition to the ability to perform the mathematical manipulations necessary to generate a correct answer. Students will be directed to justify or explain their answers on many of the questions they encounter on the AP Physics Exams. The words "justify" and "explain" indicate that the student should support the answer with prose, equations, calculations, diagrams, or graphs. The prose or equations may in some cases refer to fundamental ideas or relations in physics, such as Newton's laws, conservation of energy, Gauss' law, or Bernoulli's equation. In other cases, the justification or explanation may take the form of analyzing the behavior of an equation for large or small values of a variable in the equation.

The words "calculate," "what is," "determine," and "derive" have distinct meanings on the AP Physics Exams. "Calculate" means that a student is expected to show work leading to a final answer, which may be algebraic, but which is more often numerical. "What is" and "determine" indicate that work need not necessarily be explicitly shown to obtain full credit. Showing work leading to answers is a good idea, as it may earn a student partial credit in the case of an incorrect answer, but this step may be skipped by the confident or harried student. "Derive" is more specific, and indicates that the students need to begin their solution with one or more fundamental equations, such as those given on the AP Physics Exam equation sheet. The final answer, usually algebraic, is then obtained through the appropriate use of mathematics.

Additional information about study skills and test-taking strategies can be found at AP Central.

Calculators and Equation Tables

Policies regarding the use of calculators on the examinations take into account the expansion of the capabilities of scientific calculators, which now include not only programming and graphing functions but also the availability of stored equations and other data. For taking the sections of the examinations in which calculators are permitted, students should be allowed to use the calculators to which they are accustomed, except as noted below.* On the other hand, they should not have access to information in their calculators that is not available to other students, if that information is needed to answer the questions.

Calculators are NOT permitted on the multiple-choice sections of the Physics B and Physics C Exam. The purpose of the multiple-choice sections is to assess the breadth of students' knowledge and understanding of the basic concepts of physics. The multiple-choice questions emphasize conceptual understanding and qualitative applications.

***Exceptions to calculator use.** Although most calculators are permitted on the free-response sections, they cannot be shared with other students, and calculators with typewriter-style (QWERTY) keyboards will not be permitted on any part of the exams.

However, many physical definitions and principles are quantitative by nature and can therefore be expressed as equations. The knowledge of these basic definitions and principles, expressed as equations, is a part of the content of physics that should be learned by physics students and will continue to be assessed in the multiple-choice sections. However, any numeric calculations using these equations required in the multiple-choice sections will be kept simple. Also, in some questions, the answer choices differ by several orders of magnitude so that the questions can be answered by estimation. Students should be encouraged to develop their skills not only in estimating answers but also in recognizing answers that are physically unreasonable or unlikely.

Calculators are allowed on the <u>free-response section</u> of both examinations. Any programmable or graphing calculator may be used except as noted below*, and students will <u>not be required to erase their calculator memories</u> before and after the examination. The free-response sections emphasize solving in-depth problems where knowledge of which principles to apply and how to apply them is the most important aspect of the solution to these problems.

Regardless of the type of calculator allowed, the examinations are designed and graded to minimize the necessity of doing lengthy calculations. Except for some fundamental constants, most numerical values are selected so that calculations with them are simple and can be done quickly. When free-response problems involve calculations, most of the points awarded in the grading of the solution are given for setting up the solution correctly rather than for actually carrying out the computation.

<u>Tables containing commonly used physics equations are printed on the green insert</u> provided with each examination for students to use when taking the free-response section. The equation tables may NOT be used when taking the multiple-choice section. The Table of Information and the equation tables for the 2004 and 2005 examinations are included as an insert in this booklet so that they can easily be removed and duplicated for use by students. In general, the tables for each year's exam will be printed and distributed with the Course Description at least a year in advance so that students can become accustomed to using them throughout the year. However, since the equations will be provided with the exams, students are NOT allowed to bring their own copies to the examination room.

***Exceptions to calculator use.** Although most calculators are permitted on the free-response sections, they cannot be shared with other students, and calculators with typewriter-style (QWERTY) keyboards will not be permitted on any part of the exams.

One of the purposes of providing the commonly used equations is to make the free-response sections equitable for those students who do not have access to equations stored in their calculators. The availability of these equations means that in the grading of the free-response sections little or no credit will be awarded for simply writing down correct equations or for ambiguous answers unsupported by explanations or logical development.

The equations in the tables express relationships that are encountered most frequently in AP Physics courses and examinations. However, they do not include all equations that might possibly be used. For example, they do not include many equations that can be derived by combining others in the tables. Nor do they include equations that are simply special cases of any that are in the tables. Students are responsible for understanding the physical principles that underlie each equation and for knowing the conditions for which each equation is applicable.

The equations are grouped in tables according to major content category. Within each table, the symbols used for the variables in that table are defined. However, in some cases the same symbol is used to represent different quantities in different tables. It should be noted that there is no uniform convention among textbooks for the symbols used in writing equations. The equation tables follow many common conventions, but in some cases consistency was sacrificed for the sake of clarity.

It should also be noted that, beginning with the 2002 examinations, a change in the convention used for the sign of work in thermal physics affected some of the equations in the Physics B list. The symbol W is now defined as the work done on a thermodynamic system, rather than the work done by a system as before. This convention makes the treatment of work consistent with the work-energy theorem in mechanics, which states that the work done on a particle equals the change in the particle's kinetic energy. With this convention the first law of thermodynamics is basically a statement that adding heat to a system and doing work on it are alternate ways of increasing its energy. Since thermal physics is not a Physics C topic, this change in convention did not apply to the Physics C examination. Further information about this change can be found in the article "A Consistent Sign Convention for Work," published in *The Physics Teacher*, Vol. 38, No. 3, page 160 (March 2000).

In summary, the purpose of minimizing numerical calculations in both sections of the examinations and providing equations with the free-response sections is to place greater emphasis on the understanding and application of fundamental physical principles and concepts. For solving problems, a sophisticated programmable or graphing calculator, or the availability of stored equations, is no substitute for a thorough grasp of the physics involved.

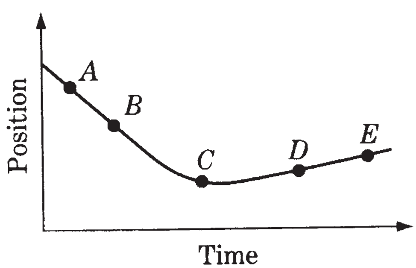
Physics B: Sample Multiple-Choice Questions

Most of the following sample questions, illustrative of the Physics B examination, have appeared in past examinations. The answers are on page 35.

Note: Units associated with numerical quantities are abbreviated, using the abbreviations listed in the table of information included with the exams (see insert in this booklet.) To simplify calculations, you may use $g = 10\ \text{m/s}^2$ in all problems.

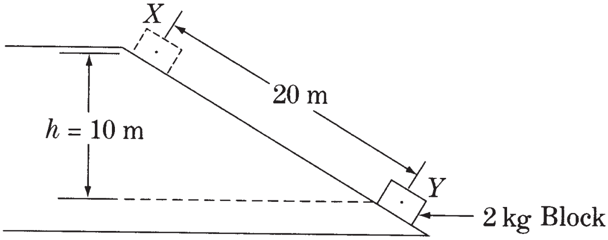
Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case.

1. An object is thrown with a horizontal velocity of 20 m/s from a cliff that is 125 m above level ground. If air resistance is negligible, the time that it takes the object to fall to the ground from the cliff is most nearly
   (A) 3 s
   (B) 5 s
   (C) 6 s
   (D) 12 s
   (E) 25 s



2. The motion of a particle along a straight line is represented by the position *versus* time graph above. At which of the labeled points on the graph is the magnitude of the acceleration of the particle greatest?
   (A) *A*
   (B) *B*
   (C) *C*
   (D) *D*
   (E) *E*

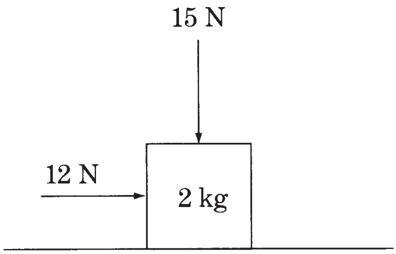
Questions 3-4



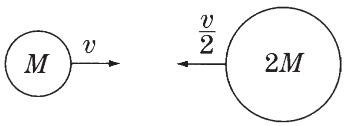
A 2 kg block, starting from rest, slides 20 m down a frictionless inclined plane from X to Y, dropping a vertical distance of 10 m as shown above.

3. The magnitude of the net force on the block while it is sliding is most nearly
   (A) 0.1 N
   (B) 0.4 N
   (C) 2.5 N
   (D) 5.0 N
   (E) 10.0 N

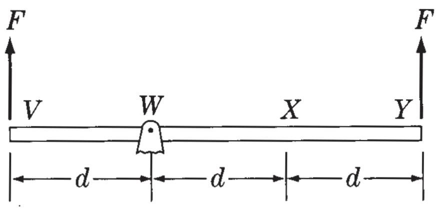
4. The speed of the block at point Y is most nearly
   (A) 7 m/s
   (B) 10 m/s
   (C) 14 m/s
   (D) 20 m/s
   (E) 100 m/s



5. A block of mass 2 kg slides along a horizontal tabletop. A horizontal applied force of 12 N and a vertical applied force of 15 N act on the block, as shown above. If the coefficient of kinetic friction between the block and the table is 0.2, the frictional force exerted on the block is most nearly
   (A) 1 N
   (B) 3 N
   (C) 4 N
   (D) 5 N
   (E) 7 N

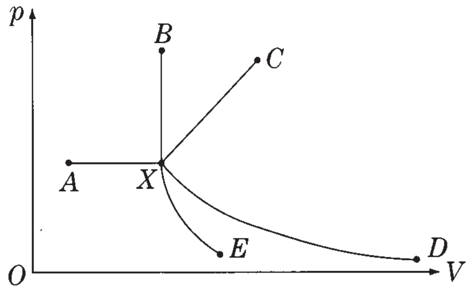


6. A ball of mass M and speed v collides head-on with a ball of mass $2M$ and speed $\frac{v}{2}$, as shown above. If the two balls stick together, their speed after the collision is
   (A) 0
   (B) $\frac{v}{2}$
   (C) $\frac{\sqrt{2}v}{2}$
   (D) $\frac{\sqrt{3}v}{2}$
   (E) $\frac{3v}{2}$



7. A massless rigid rod of length $3d$ is pivoted at a fixed point W, and two forces each of magnitude F are applied vertically upward as shown above. A third vertical force of magnitude F may be applied, either upward or downward, at one of the labeled points. With the proper choice of direction at each point, the rod can be in equilibrium if the third force of magnitude F is applied at point
(A) W only
(B) Y only
(C) V or X only
(D) V or Y only
(E) V, W, or X

8. An ideal monatomic gas is compressed while its temperature is held constant. What happens to the internal energy of the gas during this process, and why?
(A) It decreases because the gas does work on its surroundings.
(B) It decreases because the molecules of an ideal gas collide.
(C) It does not change because the internal energy of an ideal gas depends only on its temperature.
(D) It increases because work is done on the gas.
(E) It increases because the molecules travel a shorter path between collisions.

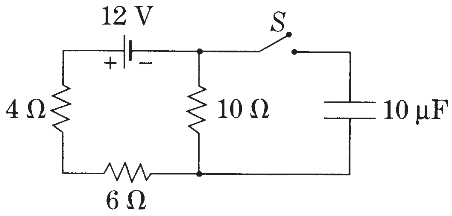


9. In the pV diagram above, the initial state of a gas is shown at point X. Which of the curves represents a process in which no work is done on or by the gas?
   (A) XA
   (B) XB
   (C) XC
   (D) XD
   (E) XE

10. An isolated positive charge q is in the plane of the page, as shown above. The directions of the electric field vectors at points P and T, which are also in the plane of the page, are given by which of the following?

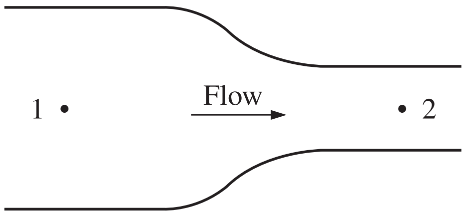
	Point P	Point T
(A)	Left	Right
(B)	Right	Left
(C)	Left	Toward the top of the page
(D)	Right	Toward the top of the page
(E)	Left	Toward the bottom of the page

Questions 11-12 relate to the following circuit in which the battery has zero internal resistance.



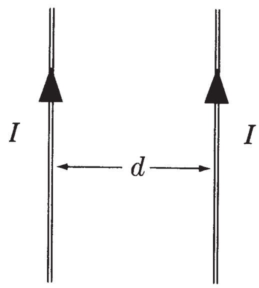
11. What is the current in the 4 | resistor while the switch S is open?
    (A) 0 A
    (B) 0.6 A
    (C) 1.2 A
    (D) 2.0 A
    (E) 3.0 A

12. When the switch S is closed and the 10 μF capacitor is fully charged, what is the voltage across the capacitor?
    (A) 0 V
    (B) 6 V
    (C) 12 V
    (D) 60 V
    (E) 120 V



13. A fluid flows steadily from left to right in the pipe shown above. The diameter of the pipe is less at point 2 then at point 1, and the fluid density is constant throughout the pipe. How do the velocity of flow and the pressure at points 1 and 2 compare?

	Velocity	Pressure
(A)	$v_1 < v_2$	$p_1 = p_2$
(B)	$v_1 < v_2$	$p_1 > p_2$
(C)	$v_1 = v_2$	$p_1 < p_2$
(D)	$v_1 > v_2$	$p_1 = p_2$
(E)	$v_1 > v_2$	$p_1 > p_2$



14. Two long parallel wires, separated by a distance d, carry equal currents I toward the top of the page, as shown above. The magnetic field due to the wires at a point halfway between them is
(A) zero in magnitude
(B) directed into the page
(C) directed out of the page
(D) directed to the right
(E) directed to the left

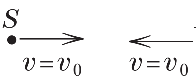
15. A source S of sound and a listener L each can be at rest or can move directly toward or away from each other with speed v_0. In which of the following situations will the observer hear the lowest frequency of sound from the source?

(A) 

(B) 

(C) 

(D) 

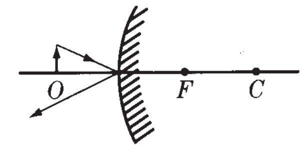
(E) 

16. The wavelength of yellow sodium light in vacuum is 5.89×10^{-7} m. The speed of this light in glass with an index of refraction of 1.5 is most nearly

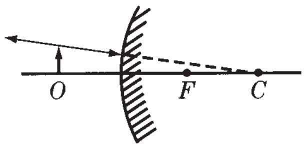
(A) 4×10^{-7} m/s
(B) 9×10^{-7} m/s
(C) 2×10^{8} m/s
(D) 3×10^{8} m/s
(E) 4×10^{8} m/s

17. An object O is in front of a convex mirror. The focal point of the mirror is labeled F and the center of curvature is labeled C. The direction of the reflected ray is correctly illustrated in all of the following EXCEPT which diagram?

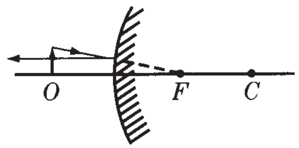
(A)



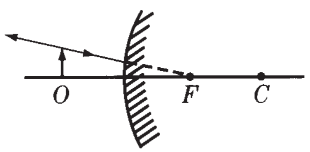
(B)



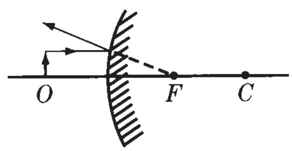
(C)



(D)



(E)



18. A system initially consists of an electron and an incident photon. The electron and the photon collide, and afterward the system consists of the electron and a scattered photon. The electron gains kinetic energy as a result of this collision. Compared with the incident photon, the scattered photon has
    (A) the same energy
    (B) a smaller speed
    (C) a larger speed
    (D) a smaller frequency
    (E) a larger frequency

19. In an experiment, light of a particular wavelength is incident on a metal surface, and electrons are emitted from the surface as a result. To produce more electrons per unit time but with less kinetic energy per electron, the experimenter should do which of the following?
    (A) Increase the intensity and decrease the wavelength of the light.
    (B) Increase the intensity and the wavelength of the light.
    (C) Decrease the intensity and the wavelength of the light.
    (D) Decrease the intensity and increase the wavelength of the light.
    (E) None of the above would produce the desired result.

20. When ^{27}Al is bombarded by neutrons, a neutron can be absorbed and an alpha particle (^{4}He) emitted. The kinetic energy of the reaction products is equal to the
    (A) kinetic energy of the incident neutron
    (B) total energy of the incident neutron
    (C) energy equivalent of the mass decrease in the reaction
    (D) energy equivalent of the mass decrease in the reaction, minus the kinetic energy of the incident neutron
    (E) energy equivalent of the mass decrease in the reaction, plus the kinetic energy of the incident neutron

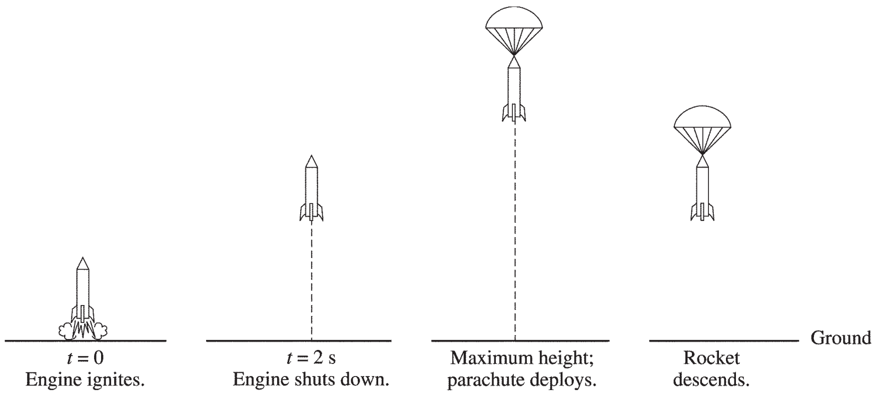
Answers to Physics B Multiple-Choice Questions

1 – B	5 – E	9 – B	13 – B	17 – D
2 – C	6 – A	10 – E	14 – A	18 – D
3 – E	7 – C	11 – B	15 – D	19 – B
4 – C	8 – C	12 – B	16 – C	20 – E

Physics B: Sample Free-Response Questions

The following seven questions constituted the complete free-response section of the 2002 AP Physics B Examination. Additional sample questions can be found at AP Central.

Directions: Answer all seven questions, which are weighted according to the points indicated. The suggested time is about 15 minutes for answering each of questions 1-4, and about 10 minutes for answering each of questions 5-7. The parts within a question may not have equal weight. Show all your work in the pink booklet in the spaces provided after each part, NOT in the green insert.



<u>Note:</u> Figures not drawn to scale.

1. (15 points)

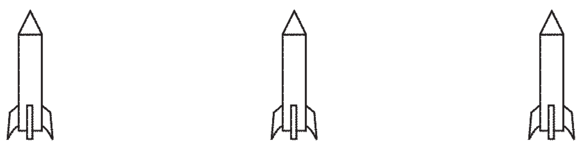
A model rocket of mass 0.250 kg is launched vertically with an engine that is ignited at time $t = 0$, as shown above. The engine provides an impulse of 20.0 N•s by firing for 2.0 s. Upon reaching its maximum height, the rocket deploys a parachute, and then descends vertically to the ground.

(a) On the figures below, draw and label a free-body diagram for the rocket during each of the following intervals.

i. While the engine is firing

ii. After the engine stops, but before the parachute is deployed

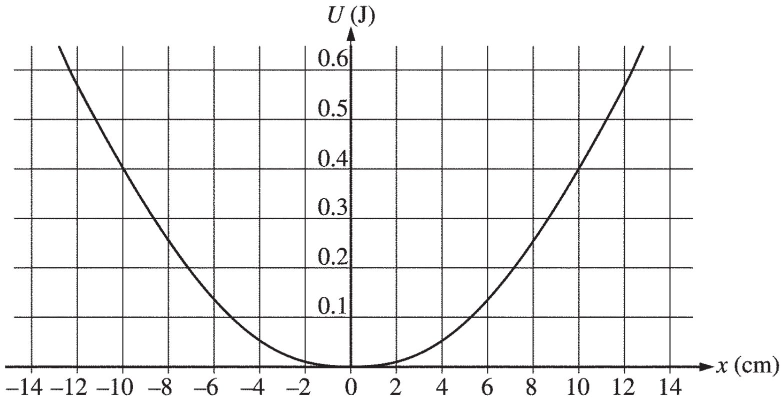
iii. After the parachute is deployed



(b) Determine the magnitude of the average acceleration of the rocket during the 2 s firing of the engine.

(c) What maximum height will the rocket reach?

(d) At what time after $t = 0$ will the maximum height be reached?



2. (15 points)

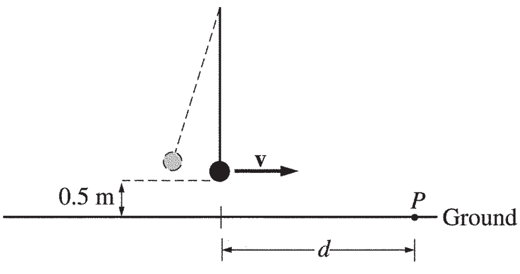
A 3.0 kg object subject to a restoring force F is undergoing simple harmonic motion with a small amplitude. The potential energy U of the object as a function of distance x from its equilibrium position is shown above. This particular object has a total energy E of 0.4 J.

(a) What is the object's potential energy when its displacement is $+4$ cm from its equilibrium position?

(b) What is the farthest the object moves along the x-axis in the positive direction? Explain your reasoning.

(c) Determine the object's kinetic energy when its displacement is -7 cm.

(d) What is the object's speed at $x = 0$?



Note: Figure not drawn to scale.

(e) Suppose the object undergoes this motion because it is the bob of a simple pendulum as shown above. If the object breaks loose from the string at the instant the pendulum reaches its lowest point and hits the ground at point P shown, what is the horizontal distance d that it travels?

3. (15 points)

Two lightbulbs, one rated 30 W at 120 V and another rated 40 W at 120 V, are arranged in two different circuits.

(a) The two bulbs are first connected in parallel to a 120 V source.

i. Determine the resistance of the bulb rated 30 W and the current in it when it is connected in this circuit.

ii. Determine the resistance of the bulb rated 40 W and the current in it when it is connected in this circuit.

(b) The bulbs are now connected in series with each other and a 120 V source.

i. Determine the resistance of the bulb rated 30 W and the current in it when it is connected in this circuit.

ii. Determine the resistance of the bulb rated 40 W and the current in it when it is connected in this circuit.

(c) In the spaces below, number the bulbs in each situation described, in order of their brightness.
(1 = brightest, 4 = dimmest)

____ 30 W bulb in the parallel circuit
____ 40 W bulb in the parallel circuit
____ 30 W bulb in the series circuit
____ 40 W bulb in the series circuit

(d) Calculate the total power dissipated by the two bulbs in each of the following cases.

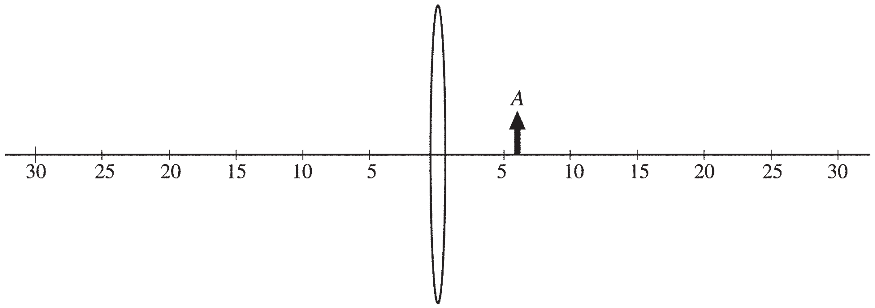
i. The parallel circuit

ii. The series circuit

4. (15 points)

A thin converging lens of focal length 10 cm is used as a simple magnifier to examine an object A that is held 6 cm from the lens.

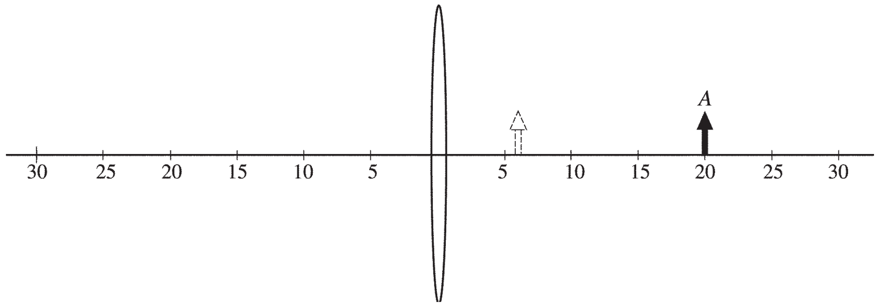
(a) On the figure below, draw a ray diagram showing the position and size of the image formed.



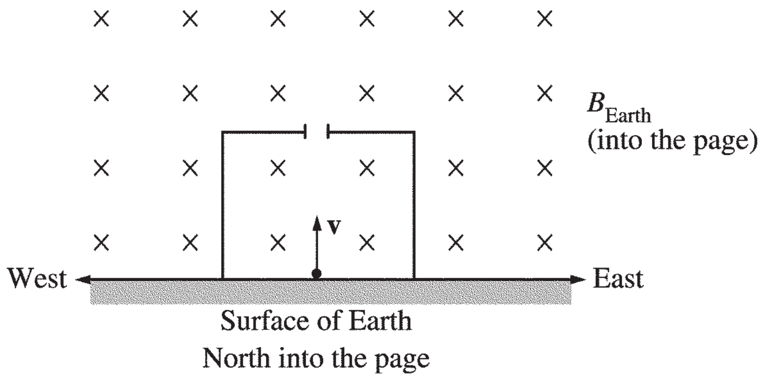
(b) State whether the image is real or virtual. Explain your reasoning.

(c) Calculate the distance of the image from the center of the lens.

(d) Calculate the ratio of the image size to the object size.



(e) The object A is now moved to the right from $x = 6$ cm to a position of $x = 20$ cm, as shown above. Describe the image position, size, and orientation when the object is at $x = 20$ cm.



5. (10 points)

A proton of mass m_p and charge e is in a box that contains an electric field E, and the box is located in Earth's magnetic field B_{Earth}. The proton moves with an initial velocity **v** vertically upward from the surface of Earth. Assume gravity is negligible.

(a) On the diagram above, indicate the direction of the electric field inside the box so that there is no change in the trajectory of the proton while it moves upward in the box. Explain your reasoning.

(b) Determine the speed of the proton while in the box if it continues to move vertically upward. Express your answer in terms of the fields and the given quantities.

The proton now exits the box through the opening at the top.

(c) On the figure on the previous page, sketch the path of the proton after it leaves the box.

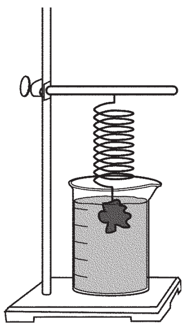
(d) Determine the magnitude of the acceleration a of the proton just after it leaves the box, in terms of the given quantities and fundamental constants.

6. (10 points)

In the laboratory, you are given a cylindrical beaker containing a fluid and you are asked to determine the density ρ of the fluid. You are to use a spring of negligible mass and unknown spring constant k attached to a stand. An irregularly shaped object of known mass m and density D ($D >> \rho$) hangs from the spring. You may also choose from among the following items to complete the task.

- A metric ruler
- A stopwatch
- String

(a) Explain how you could experimentally determine the spring constant k.



(b) The spring-object system is now arranged so that the object (but none of the spring) is immersed in the unknown fluid, as shown above. Describe any changes that are observed in the spring-object system and explain why they occur.

(c) Explain how you could experimentally determine the density of the fluid.

(d) Show explicitly, using equations, how you will use your measurements to calculate the fluid density ρ. Start by identifying any symbols you use in your equations.

Symbol	Physical quantity

7. (10 points)

A photon of wavelength 2.0×10^{-11} m strikes a free electron of mass m_e that is initially at rest, as shown above left. After the collision, the photon is shifted in wavelength by an amount $\Delta\lambda = 2h/m_ec$, and reversed in direction, as shown above right.

(a) Determine the energy in joules of the incident photon.

(b) Determine the magnitude of the momentum of the incident photon.

(c) Indicate below whether the photon wavelength is increased or decreased by the interaction.

____ Increased ____ Decreased

Explain your reasoning.

(d) Determine the magnitude of the momentum acquired by the electron.

Physics C Mechanics: Sample Multiple-Choice Questions

Most of the following sample questions, illustrative of the Physics C Mechanics examination, have appeared in past examinations. The answers are on page 48.

Note: Units associated with numerical quantities are abbreviated, using the abbreviations listed in the table of information included with the exams (see insert in this booklet.) To simplify calculations, you may use $g = 10 \text{ m/s}^2$ in all problems.

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.

Questions 1-2

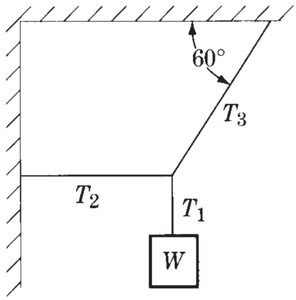
The speed v of an automobile moving on a straight road is given in meters per second as a function of time t in seconds by the following equation:

$$v = 4 + 2t^3$$

1. What is the acceleration of the automobile at $t = 2$ s?
   (A) 12 m/s^2
   (B) 16 m/s^2
   (C) 20 m/s^2
   (D) 24 m/s^2
   (E) 28 m/s^2

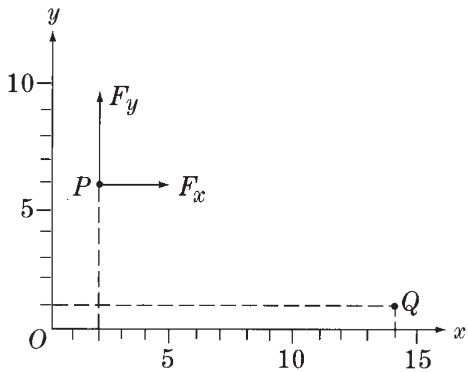
2. How far has the automobile traveled in the interval between $t = 0$ and $t = 2$ s?
   (A) 16 m
   (B) 20 m
   (C) 24 m
   (D) 32 m
   (E) 72 m

3. If a particle moves in a plane so that its position is described by the functions $x = A \cos \omega t$ and $y = A \sin \omega t$, the particle is
   (A) moving with constant speed along a circle
   (B) moving with varying speed along a circle
   (C) moving with constant acceleration along a straight line
   (D) moving along a parabola
   (E) oscillating back and forth along a straight line



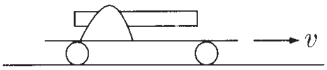
4. A system in equilibrium consists of an object of weight W that hangs from three ropes, as shown above. The tensions in the ropes are T_1, T_2, and T_3. Which of the following are correct values of T_2 and T_3?

	T_2	T_3
(A)	$W \tan 60^\circ$	$\dfrac{W}{\cos 60^\circ}$
(B)	$W \tan 60^\circ$	$\dfrac{W}{\sin 60^\circ}$
(C)	$W \tan 60^\circ$	$W \sin 60^\circ$
(D)	$\dfrac{W}{\tan 60^\circ}$	$\dfrac{W}{\cos 60^\circ}$
(E)	$\dfrac{W}{\tan 60^\circ}$	$\dfrac{W}{\sin 60^\circ}$



5. The constant force **F** with components F_x = 3 N and F_y = 4 N, shown above, acts on a body while that body moves from the point P (x = 2 m, y = 6 m) to the point Q (x = 14 m, y = 1 m). How much work does the force do on the body during this process?
   (A) 16 J
   (B) 30 J
   (C) 46 J
   (D) 56 J
   (E) 65 J

6. The sum of all the external forces on a system of particles is zero. Which of the following must be true of the system?
   (A) The total mechanical energy is constant.
   (B) The total potential energy is constant.
   (C) The total kinetic energy is constant.
   (D) The total linear momentum is constant.
   (E) It is in static equilibrium.



7. A toy cannon is fixed to a small cart and both move to the right with speed v along a straight track, as shown above. The cannon points in the direction of motion. When the cannon fires a projectile the cart and cannon are brought to rest. If M is the mass of the cart and cannon combined without the projectile, and m is the mass of the projectile, what is the speed of the projectile relative to the ground immediately after it is fired?

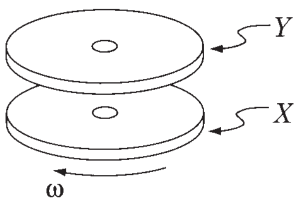
   (A) $\frac{Mv}{m}$

   (B) $\frac{(M + m)v}{m}$

   (C) $\frac{(M - m)v}{m}$

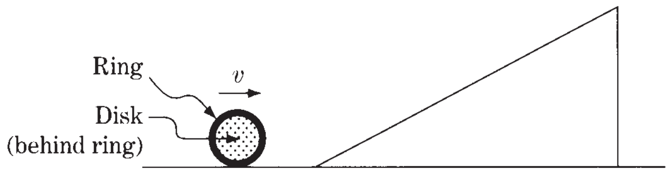
   (D) $\frac{mv}{M}$

   (E) $\frac{mv}{(M - m)}$



8. A disk X rotates freely with angular velocity ω on frictionless bearings, as shown above. A second identical disk Y, initially not rotating, is placed on X so that both disks rotate together without slipping. When the disks are rotating together, which of the following is half what it was before?

   (A) Moment of inertia of X
   (B) Moment of inertia of Y
   (C) Angular velocity of X
   (D) Angular velocity of Y
   (E) Angular momentum of both disks



9. The ring and the disk shown above have identical masses, radii, and velocities, and are not attached to each other. If the ring and the disk each roll without slipping up an inclined plane, how will the distances that they move up the plane before coming to rest compare?
   (A) The ring will move farther than will the disk.
   (B) The disk will move farther than will the ring.
   (C) The ring and the disk will move equal distances.
   (D) The relative distances depend on the angle of elevation of the plane.
   (E) The relative distances depend on the length of the plane.

10. Let g be the acceleration due to gravity at the surface of a planet of radius R. Which of the following is a dimensionally correct formula for the minimum kinetic energy K that a projectile of mass m must have at the planet's surface if the projectile is to escape from the planet's gravitational field?
   (A) $K = \sqrt{gR}$
   (B) $K = mgR$
   (C) $K = \dfrac{mg}{R}$
   (D) $K = m\sqrt{\dfrac{g}{R}}$
   (E) $K = gR$

Answers to Physics C Mechanics Multiple-Choice Questions

1 – D	3 – A	5 – A	7 – B	9 – A
2 – A	4 – E	6 – D	8 – C	10 – B

Physics C Mechanics: Sample Free-Response Questions

The following three questions constituted the complete free-response section for the Mechanics part of the 2002 AP Physics C Examination. Additional sample questions can be found at AP Central.

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part, NOT in the green insert.

Mech 1.

A crash test car of mass 1,000 kg moving at constant speed of 12 m/s collides completely inelastically with an object of mass M at time $t = 0$. The object was initially at rest. The speed v in m/s of the car-object system after the collision is given as a function of time t in seconds by the expression

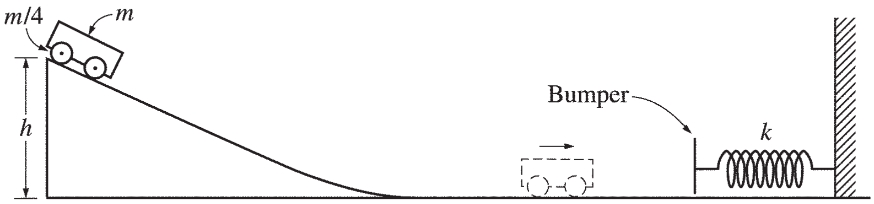
$$v = \frac{8}{1 + 5t}.$$

(a) Calculate the mass M of the object.

(b) Assuming an initial position of $x = 0$, determine an expression for the position of the car-object system after the collision as a function of time t.

(c) Determine an expression for the resisting force on the car-object system after the collision as a function of time t.

(d) Determine the impulse delivered to the car-object system from $t = 0$ to $t = 2.0$ s.



Mech 2.

The cart shown above is made of a block of mass m and four solid rubber tires each of mass $m/4$ and radius r. Each tire may be considered to be a disk. (A disk has rotational inertia $\frac{1}{2}ML^2$, where M is the mass and L is the radius of the disk.) The cart is released from rest and rolls without slipping from the top of an inclined plane of height h. Express all algebraic answers in terms of the given quantities and fundamental constants.

(a) Determine the total rotational inertia of all four tires.

(b) Determine the speed of the cart when it reaches the bottom of the incline.

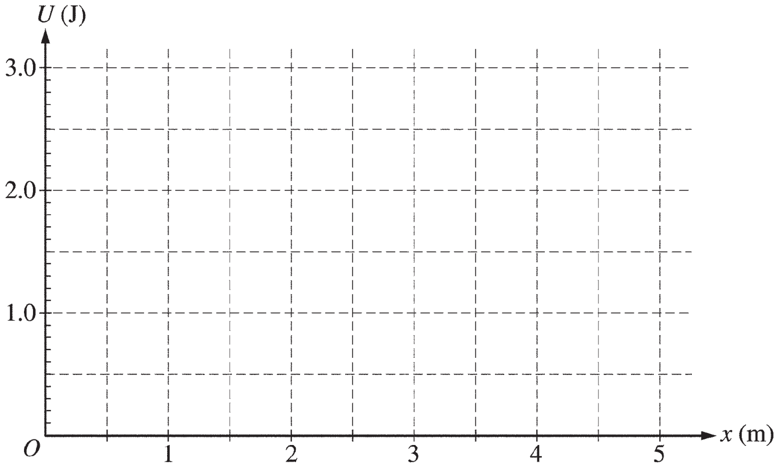
(c) After rolling down the incline and across the horizontal surface, the cart collides with a bumper of negligible mass attached to an ideal spring, which has a spring constant k. Determine the distance x_m the spring is compressed before the cart and bumper come to rest.

(d) Now assume that the bumper has a non-negligible mass. After the collision with the bumper, the spring is compressed to a maximum distance of about 90% of the value of x_m in part (c). Give a reasonable explanation for this decrease.

Mech 3.

An object of mass 0.5 kg experiences a force that is associated with the potential energy function $U(x) = \dfrac{4.0}{2.0 + x}$, where U is in joules and x is in meters.

(a) On the axes below, sketch the graph of $U(x)$ versus x.



(b) Determine the force associated with the potential energy function given above.

(c) Suppose that the object is released from rest at the origin. Determine the speed of the particle at $x = 2$ m.

In the laboratory, you are given a glider of mass 0.5 kg on an air track. The glider is acted on by the force determined in part (b). Your goal is to determine experimentally the validity of your theoretical calculation in part (c).

(d) From the list below, select the additional equipment you will need from the laboratory to do your experiment by checking the line next to each item. If you need more than one of an item, place the number you need on the line.

____ Meterstick ____ Stopwatch ____ Photogate timer

____ String ____ Spring ____ Balance

____ Wood block ____ Set of objects of different masses

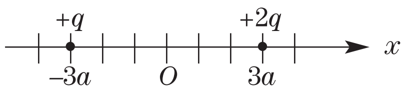
(e) Briefly outline the procedure you will use, being explicit about what measurements you need to make in order to determine the speed. You may include a labeled diagram of your setup if it will clarify your procedure.

Physics C Electricity and Magnetism: Sample Multiple-Choice Questions

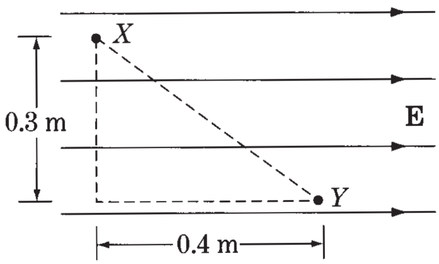
Most of the following sample questions, illustrative of the Physics C Electricity and Magnetism examination, have appeared in past examinations. The answers are on page 59.

Note: Units associated with numerical quantities are abbreviated, using the abbreviations listed in the table of information included with the exams (see insert in this booklet.)

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.

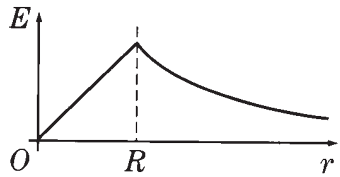


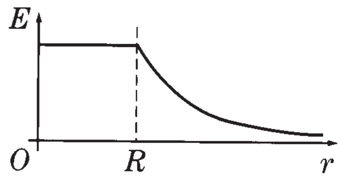
1. Two charges are located on the x-axis of a coordinate system as shown above. The charge $+2q$ is located at $x = +3a$ and the charge $+q$ is located at $x = -3a$. Where on the x-axis should an additional charge $+4q$ be located to produce an electric field equal to zero at the origin O?
   (A) $x = -6a$
   (B) $x = -2a$
   (C) $x = +a$
   (D) $x = +2a$
   (E) $x = +6a$

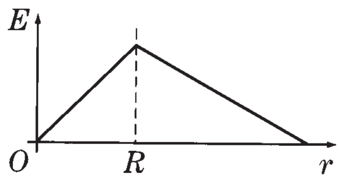


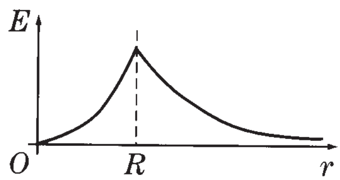
2. A uniform electric field **E** of magnitude 6,000 V/m exists in a region of space as shown above. What is the electric potential difference, $V_X - V_Y$, between points X and Y?
(A) −12,000 V
(B) 0 V
(C) 1,800 V
(D) 2,400 V
(E) 3,000 V

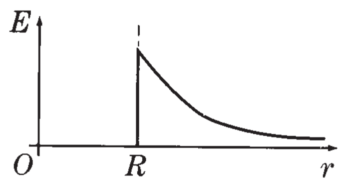
3. Charge is distributed uniformly throughout a long nonconducting cylinder of radius R. Which of the following graphs best represents the magnitude of the resulting electric field E as a function of r, the distance from the axis of the cylinder?

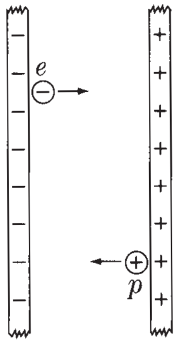
(A)


(B)


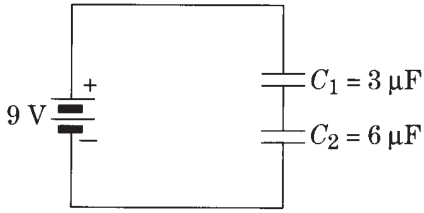
(C)


(D)


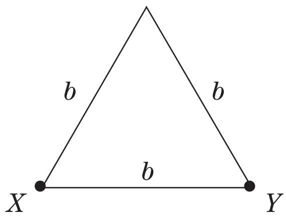
(E)




4. A proton p and an electron e are released simultaneously on opposite sides of an evacuated area between large, charged parallel plates, as shown above. Each particle is accelerated toward the oppositely charged plate. The particles are far enough apart so that they do not affect each other. Which particle has the greater kinetic energy upon reaching the oppositely charged plate?
   (A) The electron
   (B) The proton
   (C) Neither particle; both kinetic energies are the same.
   (D) It cannot be determined without knowing the value of the potential difference between the plates.
   (E) It cannot be determined without knowing the amount of charge on the plates.



5. Two capacitors initially uncharged are connected in series to a battery, as shown above. What is the charge on the top plate of C_1?
   (A) –81 μC
   (B) –18 μC
   (C) 0 μC
   (D) +18 μC
   (E) +81 μC



6. Wire of resistivity ρ and cross-sectional area A is formed into an equilateral triangle of side b, as shown above. The resistance between two vertices of the triangle, X and Y, is

(A) $\frac{3}{2}\frac{A}{\rho b}$

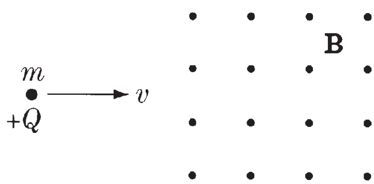
(B) $3\frac{A}{\rho b}$

(C) $\frac{2}{3}\frac{\rho b}{A}$

(D) $\frac{3}{2}\frac{\rho b}{A}$

(E) $3\frac{\rho b}{A}$

Questions 7-8



A particle of electric charge $+Q$ and mass m initially moves along a straight line in the plane of the page with constant speed v, as shown above. The particle enters a uniform magnetic field of magnitude B directed out of the page and moves in a semicircular arc of radius R.

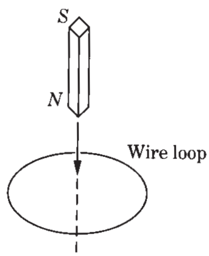
7. Which of the following best indicates the magnitude and the direction of the magnetic force **F** on the charge just after the charge enters the magnetic field?

	Magnitude	Direction
(A)	$\frac{kQ^2}{R^2}$	Toward the top of the page
(B)	$\frac{kQ^2}{R^2}$	Toward the bottom of the page
(C)	QvB	Out of the plane of the page
(D)	QvB	Toward the top of the page
(E)	QvB	Toward the bottom of the page

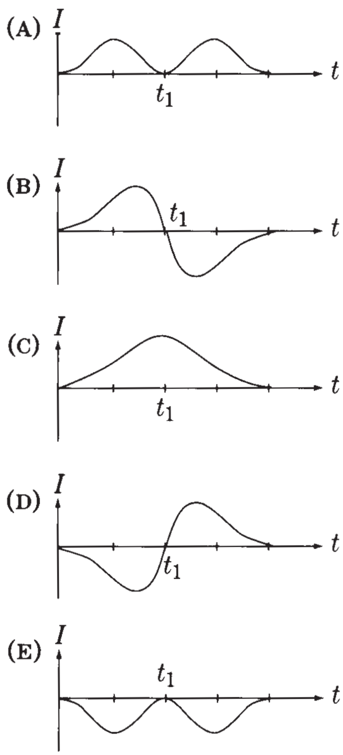
8. If the magnetic field strength is increased, which of the following will be true about the radius R?

    I. R increases if the incident speed is held constant.
    II. For R to remain constant, the incident speed must be increased.
    III. For R to remain constant, the incident speed must be decreased.

    (A) I only
    (B) II only
    (C) III only
    (D) I and II only
    (E) I and III only



9. A bar magnet is lowered at constant speed through a loop of wire as shown in the diagram above. The time at which the midpoint of the bar magnet passes through the loop is t_1. Which of the following graphs best represents the time dependence of the induced current in the loop? (A positive current represents a counterclockwise current in the loop as viewed from above.)



10. A loop of wire enclosing an area of 1.5 m^2 is placed perpendicular to a magnetic field. The field is given in teslas as a function of time t in seconds by

$$B(t) = \frac{20t}{3} - 5$$

The induced emf in the loop at t = 3 s is most nearly

(A) 0 V
(B) 5 V
(C) 10 V
(D) 15 V
(E) 20 V

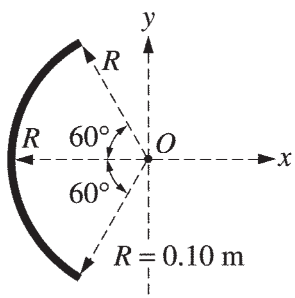
Answers to Physics C Electricity and Magnetism Multiple-Choice Questions

1 – A	3 – A	5 – D	7 – E	9 – B
2 – D	4 – C	6 – C	8 – B	10 – C

Physics C Electricity and Magnetism: Sample Free-Response Questions

The following three questions constituted the complete free-response section for the Electricity and Magnetism part of the 2002 AP Physics C Examination. Additional sample questions can be found at AP Central.

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part, NOT in the green insert.



E&M 1.

A rod of uniform linear charge density $\lambda = +1.5 \times 10^{-5}$ C/m is bent into an arc of radius $R = 0.10$ m. The arc is placed with its center at the origin of the axes shown above.

(a) Determine the total charge on the rod.

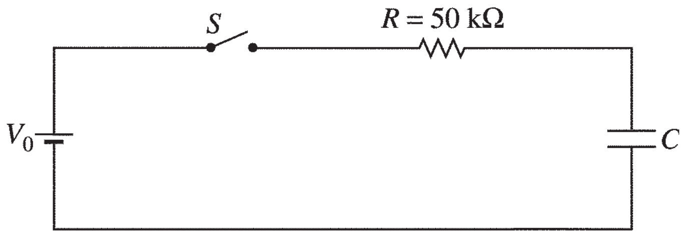
(b) Determine the magnitude and direction of the electric field at the center O of the arc.

(c) Determine the electric potential at point O.

A proton is now placed at point O and held in place. Ignore the effects of gravity in the rest of this problem.

(d) Determine the magnitude and direction of the force that must be applied in order to keep the proton at rest.

(e) The proton is now released. Describe in words its motion for a long time after its release.



E&M 2.

Your engineering firm has built the *RC* circuit shown above. The current is measured for the time t after the switch is closed at $t = 0$ and the best-fit curve is represented by the equation $I(t) = 5.20\ e^{-t/10}$, where I is in milliamperes and t is in seconds.

(a) Determine the value of the charging voltage V_0 predicted by the equation.

(b) Determine the value of the capacitance C predicted by the equation.

(c) The charging voltage is measured in the laboratory and found to be greater than predicted in part (a).

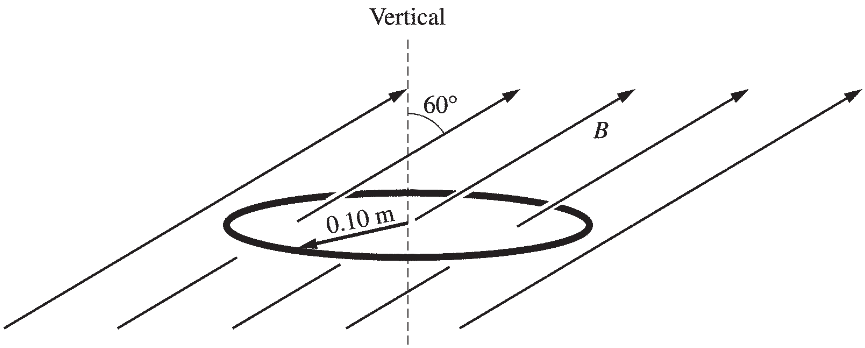
  i. Give one possible explanation for this finding.

  ii. Explain the implications that your answer to part i has for the predicted value of the capacitance.

(d) Your laboratory supervisor tells you that the charging time must be decreased. You may add resistors or capacitors to the original components and reconnect the *RC* circuit. In parts i and ii below, show how to reconnect the circuit, using either an additional resistor or a capacitor to decrease the charging time.

  i. Indicate how a resistor may be added to decrease the charging time. Add the necessary resistor and connections to the following diagram.

  ii. Instead of a resistor, use a capacitor. Indicate how the capacitor may be added to decrease the charging time. Add the necessary capacitor and connections to the following diagram.

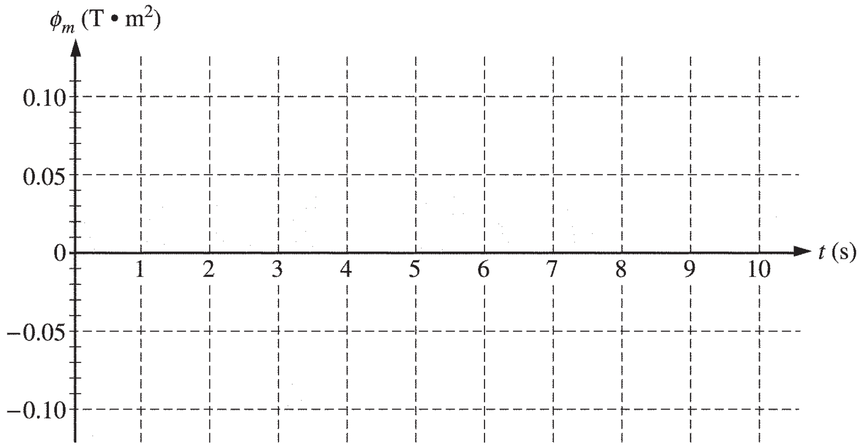


E&M 3.

A circular wire loop with radius 0.10 m and resistance 50 Ω is suspended horizontally in a magnetic field of magnitude B directed upward at an angle of 60° with the vertical, as shown above. The magnitude of the field in teslas is given as a function of time t in seconds by the equation $B = 4(1 - 0.2t)$.

(a) Determine the magnetic flux ϕ_m through the loop as a function of time.

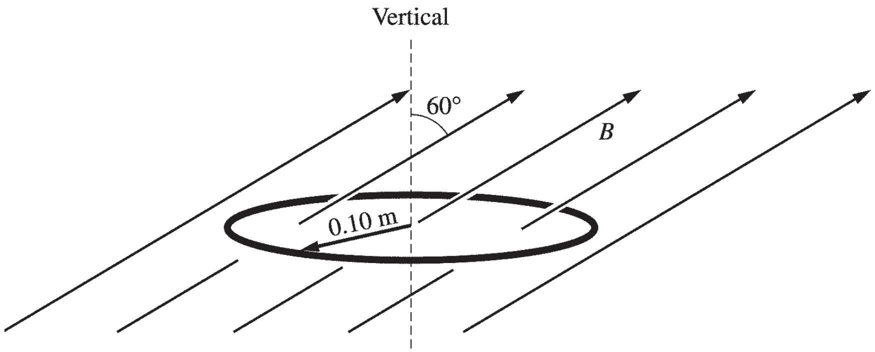
(b) Graph the magnetic flux ϕ_m as a function of time on the axes below.



(c) Determine the magnitude of the induced emf in the loop.

(d) i. Determine the magnitude of the induced current in the loop.

ii. Show the direction of the induced current on the following diagram.



(e) Determine the energy dissipated in the loop from $t = 0$ to $t = 4$ s.

AP® Program Essentials

The AP Reading

In June, the free-response sections of the exams, as well as the Studio Art portfolios, are scored by college faculty and secondary school AP teachers at the AP Reading. Thousands of readers participate, under the direction of a Chief Reader in each field. The experience offers both significant professional development and the opportunity to network with like-minded educators.

If you are an AP teacher or a college faculty member and would like to serve as a reader, you can visit AP Central for more information on how to apply. Alternatively, send an e-mail message to apreader@ets.org, or call Performance Scoring Services at 609 406-5383.

AP Grades

The readers' scores on the essay and problem-solving questions are combined with the results of the computer-scored multiple-choice questions, and the total raw scores are converted to AP's 5-point scale:

AP GRADE	QUALIFICATION
5	Extremely well qualified
4	Well qualified
3	Qualified
2	Possibly qualified
1	No recommendation

Grade Distributions

Many teachers want to compare their students' grades with the national percentiles. Grade distribution charts are available at AP Central, as is information on how the cut-off points for each AP grade are calculated. Grade distribution charts are also available on the AP student site at www.collegeboard.com/apstudents.

Earning College Credit and/or Placement

Credit, advanced placement, or both are awarded by the college or university, not the College Board or the AP Program. The best source of specific and up-to-date information about an individual institution's policy is its catalog or Web site.

Why Colleges Grant Credit and/or Placement for AP Grades

Colleges know that the AP grades of their incoming students represent a level of achievement equivalent to that of students who take the same course in the colleges' own classrooms. That equivalency is assured through several Advanced Placement Program processes:

- College faculty serve on the committees that develop the course descriptions and examinations in each AP subject.
- College faculty are responsible for standard setting and are involved in the evaluation of student responses at the AP Reading.
- AP courses and exams are updated regularly, based on both the results of curriculum surveys at up to 200 colleges and universities and the interactions of committee members with professional organizations in their discipline.
- College comparability studies are undertaken in which the performance of college students on AP Exams is compared with that of AP students to confirm that the AP grade scale of 1–5 is properly aligned with current college standards.

In addition, the College Board has commissioned studies that use a "bottom-line" approach to validating AP Exam grades by comparing the achievement of AP versus non-AP students in higher-level college courses. For example, in the 1998 Morgan and Ramist "21-College" study, AP students who were exempted from introductory courses and who completed a higher-level course in college were compared favorably, on the basis of their college grades, with students who completed the prerequisite first course in college, then took the second, higher-level course in the subject area. Such studies answer the question of greatest concern to colleges — are AP students who are exempted from introductory courses as well prepared to continue in a subject area as students who took their first course in college? To see the results of several college validity studies, go to AP Central. (The Morgan and Ramist study can be downloaded from the site in its entirety.)

Guidelines on Granting Credit and/or Placement for AP Grades

If you are an admissions administrator and need guidance on setting an AP policy for your college or university, you will find the *College and University Guide to the Advanced Placement Program* useful; see the back of this booklet for ordering information. Alternatively, contact your local College Board office, as noted on the inside back cover of this Course Description.

Finding Colleges That Accept AP Grades

In addition to contacting colleges directly for their AP policies, students and teachers can use College Search, an online resource maintained by the College Board through its Annual Survey of Colleges. College Search can be accessed via the College Board's Web site (www.collegeboard.com). It is worth remembering that policies are subject to change. Contact the college directly to get the most up-to-date information.

AP Awards

The AP Program offers a number of awards to recognize high school students who have demonstrated college-level achievement through AP courses and exams. Although there is no monetary award, in addition to an award certificate, student achievement is acknowledged on any grade report sent to colleges following the announcement of the awards. For detailed information on AP Awards, including qualification criteria, visit AP Central or contact the College Board's National Office. Students can find this information at www.collegeboard.com/apstudents.

AP Calendar

The *AP Program Guide* and the *Bulletin for AP Students and Parents* provide education professionals and students, respectively, with information on the various events associated with the AP year. Information on ordering and downloading these publications can be found at the back of this booklet.

Test Security

The entire AP Exam must be kept secure at all times. Forty-eight hours after the exam has been administered, the green and blue inserts containing the free-response questions (Section II) can be made available for teacher and student review.* **However, the multiple-choice section (Section I) MUST remain secure both before and after the exam administration.** No one other than students taking the exam can ever have access to or see the questions contained in Section 1 — this includes AP Coordinators and all teachers. The multiple-choice section must never be shared, copied in any manner, or reconstructed by teachers and students after the exam.

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*The alternate form of the free-response section (used for late testing administration) is NOT released.

Selected multiple-choice questions are reused from year to year to provide an essential method of establishing high exam reliability, controlled levels of difficulty, and comparability with earlier exams. These goals can be attained only when the multiple-choice questions remain secure. This is why teachers cannot view the questions and students cannot share information about these questions with anyone following the exam administration.

To ensure that all students have an equal opportunity to demonstrate their abilities on the exam, AP Exams must be administered in a uniform manner. **It is extremely important to follow the administration schedule and all procedures outlined in detail in the most recent *AP Coordinator's Manual*.** Please note that Studio Art portfolios and their contents are not considered secure testing materials; see the *AP Coordinator's Manual* for further information. The manual also includes directions on how to deal with misconduct and other security problems. Any breach of security should be reported to Test Security immediately (call 800 353-8570, fax 609 406-9709, or e-mail tsreturns@ets.org).

Teacher Support

You can find the following Web resources at AP Central:

- Teachers' Resources (reviews of classroom resources).
- Institutes & Workshops (a searchable database of professional development opportunities).
- The most up-to-date and comprehensive information on AP courses, exams, and other Program resources.
- The opportunity to exchange teaching methods and materials with the international AP community using electronic discussion groups (EDGs).
- An electronic library of AP publications, including released exam questions, the *AP Coordinator's Manual*, Course Descriptions, and sample syllabi.
- Opportunities for professional involvement in the AP Program.
- Information about state and federal support for the AP Program.
- AP Program data, research, and statistics.
- FAQs about the AP Program.
- Current news and features about the AP Program, its courses and teachers.

AP teachers can also use a number of AP publications, CD-ROMs, and videos that supplement these Web resources. Please see the following pages for an overview and ordering information.

Pre-AP®

Pre-AP® is a suite of K–12 professional development resources and services to equip middle and high school teachers with the strategies and tools they need to engage their students in high-level learning, thereby ensuring that every middle and high school student has the depth and understanding of the skills, habits of mind, and concepts they need to succeed in college.

Pre-AP rests upon a profound hope and heartfelt esteem for teachers and students. Conceptually, Pre-AP is based on two important premises. The first is the expectation that all students can perform at rigorous academic levels. This expectation should be reflected in curriculum and instruction throughout the school such that all students are consistently being challenged to expand their knowledge and skills to the next level.

The second is the belief that we can prepare every student for higher intellectual engagement by starting the development of skills and acquisition of knowledge as early as possible. Addressed effectively, the middle and high school years can provide a powerful opportunity to help all students acquire the knowledge, concepts, and skills needed to engage in a higher level of learning.

Since Pre-AP teacher professional development supports explicitly the goal of college as an option for every student, it is important to have a recognized standard for college-level academic work. The Advanced Placement Program (AP) provides these standards for Pre-AP. Pre-AP teacher professional development resources reflect topics, concepts, and skills found in AP courses.

The College Board does not design, develop, or assess courses labeled "Pre-AP." Courses labeled "Pre-AP" that inappropriately restrict access to AP and other college-level work are inconsistent with the fundamental purpose of the Pre-AP initiatives of the College Board. We encourage schools, districts, and policymakers to utilize Pre-AP professional development in a manner that ensures equitable access to rigorous academic experiences for all students.

Pre-AP Professional Development

Pre-AP professional development is administered by Pre-AP Initiatives, a unit in K–12 Professional Development, and is available through workshops and conferences coordinated by the regional offices of the College Board. Pre-AP professional development is divided into two categories:

1. **Articulation of content and pedagogy across the middle and high school years —** The emphasis of professional development in this category is aligning curriculum and improving teacher communication. The intended outcome from articulation is a coordinated program of teaching skills and concepts over several years.
2. **Classroom strategies for middle and high school teachers —** Various approaches, techniques, and ideas are emphasized in professional development in the category.

For a complete list of Pre-AP Professional Development offerings, please contact your regional office or visit AP Central at apcentral.collegeboard.com.

AP Publications and Other Resources

A number of AP resources 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 identify resources that may be of particular use to you, refer to the following key.

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

Ordering Information

You have several options for ordering publications:

- **Online.** Visit the College Board store at store.collegeboard.com.
- **By mail.** Send a completed order form with your payment or credit card information to: Advanced Placement Program, Dept. E-06, P. O. Box 6670, Princeton, NJ 08541-6670. If you need a copy of the order form, you can download one from AP Central.

- **By fax.** Credit card orders can be faxed to AP Order Services at 609 771-7385.
- **By phone.** Call AP Order Services at 609 771-7243, Monday through Friday, 8:00 a.m. to 9:00 p.m. ET. Have your American Express, Discover, JCB, MasterCard, or VISA information ready. This phone number is for credit card orders only.

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 UPS ground rate postage (or its equivalent) on all prepaid orders; delivery generally takes two to three weeks. Please do not use P.O. Box numbers. Postage will be charged on all orders requiring billing and/or requesting a faster method of delivery.

Publications may be returned for a full refund if they are returned within 30 days of invoice. Software and videos may be exchanged within 30 days if they are opened, or returned for a full refund if they are unopened. No collect or C.O.D. shipments are accepted. Unless otherwise specified, orders will be filled with the currently available edition; prices and discounts are subject to change without notice.

In compliance with Canadian law, all AP publications delivered to Canada incur the 7 percent GST. The GST registration number is 13141 4468 RT. Some Canadian schools are exempt from paying the GST. Appropriate proof of exemption must be provided when AP publications are ordered so that tax is not applied to the billing statement.

Print

Items marked with a computer mouse icon can be downloaded for free from AP Central.

Bulletin for AP Students and Parents **SP**

This bulletin provides a general description of the AP Program, including how to register for AP courses, and information on the policies and procedures related to taking the exams. It describes each AP Exam, lists the advantages of taking the exams, describes the grade reporting process, and includes the upcoming exam schedule. The *Bulletin* is available in both English and Spanish.

AP Program Guide **A**

This guide takes the AP Coordinator step-by-step through the school year — from organizing an AP program, through ordering and administering the AP Exams, payment, and grade reporting. It also includes information on teacher professional development, AP resources, and exam schedules. The *AP Program Guide* is sent automatically to all schools that register to participate in AP.

College and University Guide to the AP Program **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 **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. Note: The Course Description for AP Computer Science is available in electronic format only.

Pre-AP **A, T**

This brochure describes the Pre-AP concept and the professional development opportunities available to middle school and high school teachers.

Released Exams **T**

About every four to five years, on a rotating schedule, the AP Program releases a complete copy of each exam. In addition to providing the multiple-choice questions and answers, the publication describes the process of scoring the free-response questions and includes examples of students' actual responses, the scoring guidelines, and commentary that explains why the responses received the scores they did.

Teacher's Guides **T**

For those about to teach an AP course for the first time, or for experienced AP teachers who would like to get some fresh ideas for the classroom, the Teacher's Guide is an excellent resource. Each Teacher's Guide contains syllabi developed by high school teachers currently teaching the

AP course and college faculty who teach the equivalent course at colleges and universities. Along with detailed course outlines and innovative teaching tips, you'll also find extensive lists of suggested 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. To help teachers and administrators who are interested in establishing an APVT at their school, the College Board has published these guides: *A Guide for Advanced Placement English Vertical Teams*; *Advanced Placement Program Mathematics Vertical Teams Toolkit*; *AP Vertical Teams in Science*, *Social Studies*, *Foreign Language*, *Studio Art*, *and Music Theory: An Introduction*; *AP Vertical Teams Guide for Social Studies; AP Vertical Teams Guide for Fine Arts*, *Vol.1: Studio Art*; *AP Vertical Teams Guide for Fine Arts*, *Vol. 2: Music Theory*; and *AP Vertical Teams Guide for Fine Arts*, *Vol.1 and 2* (set).

Multimedia

APCD® (home version),
(multi-network site license) **SP, T**

These CD-ROMs are available for Calculus AB, English Language, English Literature, European History, Spanish Language, and U.S. History. 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 to help students schedule and organize their study time.

The teacher version of each CD, which can be licensed for up to 50 workstations, enables you to monitor student progress and provide individual feedback. Included is a Teacher's Manual that gives full explanations along with suggestions for utilizing the APCD in the classroom.

College Board Offices

National Office
45 Columbus Avenue, New York, NY 10023-6992
212 713-8066
E-mail: ap@collegeboard.org

Middle States
Serving Delaware, District of Columbia, Maryland, New Jersey, New York, Pennsylvania, and Puerto Rico
Two Bala Plaza, Suite 900, Bala Cynwyd, PA 19004-1501
610 670-4400
E-mail: msro@collegeboard.org

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Canada
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250 861-9050; 800 667-4548 in Canada only
E-mail: gewonus@collegeboard.org

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