The College Board

AP® ADVANCED PLACEMENT PROGRAM®

Course Description

PHYSICS

Physics B, Physics C

PH

MAY 2002, MAY 2003

The College Board is a national nonprofit membership association dedicated to preparing, inspiring, and connecting students to college and opportunity. Founded in 1900, the association is composed of more than 4,200 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.

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.

The College Board acknowledges that Dr. Tommy J. Boley, in his publication “New Trends in Teaching Composition” (1985) and in other writings has formulated the S.O.A.P. method of teaching composition in primary and secondary schools.

For further information, visit http://apcentral.collegeboard.com.

Dear Colleagues:

Last year more than three quarters of a million high school students benefited from the opportunity of studying in AP courses and then taking the challenging AP Exams. These students experienced the power of learning as it comes alive in the classroom, as well as the practical benefits of earning college credit and placement while still in high school. Behind each of these students was a talented, hardworking teacher. Teachers are the secret to the success of AP. They are the heart and soul of the Program.

The College Board is committed to supporting the work of AP teachers in as many ways as possible. AP workshops and Summer Institutes held around the globe provide stimulating professional development for 60,000 teachers each year. The College Board Fellows stipends provide funds to support many teachers' attendance at these institutes, and in 2001, stipends were offered for the first time to teams of Pre-AP™ teachers as well.

Perhaps most exciting, the College Board continues to expand an interactive Web site designed specifically to support AP teachers. At this Internet site, teachers have access to a growing array of classroom resources, from textbook reviews to lesson plans, from opinion polls to cutting-edge exam information. I invite all AP teachers, particularly those who are new to the Program, to take advantage of these resources.

This AP Course Description provides an outline of content and description of course goals, while still allowing teachers the flexibility to develop their own lesson plans and syllabi, and to bring their individual creativity to the AP classroom. Additional resources, including sample syllabi, can be found in the AP Teacher's Guide that is available for each AP subject.

As we look to the future, the College Board's goal is to provide access to AP courses in every high school. Reaching this goal will require a lot of hard work. We encourage you to help us build bridges to college and opportunity by finding ways to prepare students in your school to benefit from participation in AP.

Sincerely,

Gaston Caperton
President
The College Board

Contents

Welcome to the AP Program

The Advanced Placement Program is sponsored by the College Board, a non-profit membership association. AP offers 35 college-level courses and exams in 19 subject areas for highly motivated students in secondary schools. Its reputation for excellence results from the close cooperation among secondary schools, colleges, and the College Board. More than 2,900 universities and colleges worldwide grant credit, advanced placement, or both to students who have performed satisfactorily on the exams, and 1,400 institutions grant sophomore standing to students who meet their requirements. Approximately 13,000 high schools throughout the world participate in the AP Program; in May 2000, they administered more than 1.3 million AP Exams.

You will find more information about the AP Program at the back of this Course Description, and at www.collegeboard.com/ap. This Web site is maintained for the AP Program by collegeboard.com, a destination Web site for students and parents.

AP Courses

AP courses are available in the subject areas listed on the next page. (Unless noted, an AP course is equivalent to a full-year college course.) Each course is developed by a committee composed of college faculty and AP teachers. Members of these Development Committees are appointed by the College Board and serve for overlapping terms of up to four years.

AP Exams

For each AP course, an AP Exam is administered at participating schools and multischool centers worldwide. Schools register to participate by completing the AP Participation Form and agreeing to its conditions. For more details, see *A Guide to the Advanced Placement Program*; information about ordering and downloading this publication can be found at the back of this booklet.

Except for Studio Art — which consists of a portfolio assessment — all exams contain a free-response section (either essay or problem-solving) and another section consisting of multiple-choice questions. The modern language exams also contain a speaking component, and the Music Theory exam includes a sight-singing task.

AP Subject Areas	AP Courses and Exams
Art	Art History; Studio Art: Drawing Portfolio; Studio Art: 2-D Portfolio; Studio Art: 3-D Portfolio
Biology	Biology
Calculus	AB; BC
Chemistry	Chemistry
Computer Science	A*; AB
Economics	Macroeconomics*; Microeconomics*
English	Language and Composition; Literature and Composition; International English Language (APIEL™)
Environmental Science	Environmental Science*
French	Language; Literature
German	Language
Geography	Human Geography*
Government and Politics	Comparative*; United States*
History	European; United States; World
Latin	Literature; Vergil
Music	Music Theory
Physics	B; C: Electricity and Magnetism*; C: Mechanics*
Psychology	Psychology*
Spanish	Language; Literature
Statistics	Statistics*

* This subject is the equivalent of a half-year college course.

Equity and Access

The College Board and the Advanced Placement Program encourage teachers, AP Coordinators, and school administrators to make equity and access guiding principles 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. The Board encourages the elimination of barriers that restrict access to AP courses for students from ethnic and racial groups that have been traditionally underrepresented in the AP Program.

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

Introduction to AP Physics

Shaded text indicates important new changes in 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, 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 principles 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 16-20, 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 physics is viewed primarily from a cultural or historical perspective. Emphasis is on a qualitative understanding of general principles and models and on the nature of scientific inquiry. Students in such courses are generally oriented toward the humanities and desire the development of an understanding of the historical role of science and its place in contemporary society. The level of mathematical sophistication expected may extend to simple trigonometry, but rarely beyond. These courses vary widely in content and approach, and at present there is no AP Examination for courses in this category.

The *Physics B* course provides a systematic introduction to the main principles of physics and emphasizes the development of problem-solving ability. 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 with a laboratory component and is not the usual preparation for more advanced physics and engineering courses. However, the B course often provides 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 *Physics C* course ordinarily forms the first part of 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 that in the B course. Strong emphasis is placed on solving a variety of challenging problems, some requiring calculus. The subject matter of the C course is principally mechanics, and electricity and magnetism, with approximately equal emphasis on these two areas. The C course is the first part of a sequence that is sometimes a very intensive one-year course in college but that often extends over one and one-half to two years, with a laboratory component.

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.

Student and 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 nonscience 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. Candidates 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, 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.

Instructional Approaches

Secondary school programs for the achievement of AP course goals can take several forms. The strongly recommended format for both Physics B and Physics C courses is a second-year course following the usual introductory physics course. A first-year course that permits students to explore concepts in the laboratory provides a richer experience in the process of science and better prepares them for more analytical approaches taken in AP courses. In some schools, AP Physics has been taught successfully as a very intensive first-year course; but in this case, some students may not have enough time to develop thorough conceptual understandings or to have sufficient enriching laboratory experiences. Independent study for individual, highly motivated students is a third possibility that can be successfully implemented.

The imaginative teacher can combine these and other possible approaches to fit the needs of his or her students. More detailed descriptions about such alternate approaches can be found in the Teacher's Guide. However, because of the nature of the AP course, whichever approach is taken, the teacher needs time for extra preparation for both class and laboratory and should have a teaching load that is adjusted accordingly.

A one-year AP Physics 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. In a school that employs block scheduling, it is strongly recommended that AP Physics be scheduled to extend over an entire year.

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 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

In addition to the questionnaire, the survey asked the colleges to return syllabi for their introductory courses. An analysis of the syllabi, including information about the specific lab experiments performed and the topics covered by the college labs will be included in a more extensive laboratory guide in the next edition of the Teacher's Guide: check the AP Web site for the availability of this and other publications. 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.

Coletta, Vincent P., *College Physics*, 1st ed. New York: WCB/McGraw Hill, 1995.

Cutnell, John D. and Kenneth W. Johnson, *Physics*, 5th ed. New York: John Wiley & Sons, 2001.

Giancoli, Douglas C., *Physics: Principles with Applications*, 5th ed. Upper Saddle River, N.J.: Prentice-Hall, 1998.

Hecht, Eugene, *Physics: Algebra/Trigonometry*, 2nd ed. Pacific Grove, CA, Brooks Cole Publishing, 1998.

Jones, Edwin R. and Richard L. Childers, *Contemporary College Physics*, 3rd ed. Boston: WCB/McGraw Hill, 1999. (updates in 2001)

Sears, Francis W., Mark W. Zemansky, and Hugh D. Young, *College Physics*, 7th ed. Reading, Mass.: Addison Wesley Longman, 1991.

Serway, Raymond A. and Jerry S. Faughn, *College Physics*, 5th ed. Fort Worth: Saunders, 1999.

Wilson, Jerry D. and Anthony J. Buffa, *College Physics*, 4th ed. Upper Saddle River, NJ, Prentice Hall, 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.

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 16–20 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 with the 2002 examination, fluid mechanics will be added to the topics covered in the Physics B course, as previously noted, primarily because many similar college courses also cover this area. Approximately 5% of the exam will be devoted to fluids. To make room for this addition, the portion of the exam covering atomic and nuclear physics will be reduced from 15% to 10%, mainly by the elimination of questions on alpha particle scattering and the Rutherford model, the Bohr model of the atom (although atomic energy levels will still be covered), and radioactivity and half life.

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.

Crummett, William P. and Arthur B. Western, *University Physics: Models and Applications*, 1st ed. New York: WCB/McGraw Hill, 1994.

Fishbane, Paul M., Stephen Gasiorowicz, and Stephen T. Thornton, *Physics for Scientists and Engineers*, 2nd ed. Upper Saddle River, N.J.: Prentice Hall, 1996.

Halliday, David, Robert Resnick, and Jearl Walker, *Fundamentals of Physics*, 6th ed. New York: John Wiley, 2001.

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

Serway, R. A. and Robert Beichner, *Physics for Scientists and Engineers*, 5th ed. Forth Worth: Saunders, 2000.

Serway, R. A., *Principles of Physics*, 2nd ed. Forth Worth: Saunders, 1998.

Sanny, Jeff and William Moebs, *University Physics*, 1st ed. New York: WCB/McGraw Hill, 1996.

Tipler, Paul A., *Physics for Scientists and Engineers*, 4th ed. New York: Freeman/Worth, 1999.
Wolfson, Richard, and Jay M. Pasachoff, *Physics for Scientists and Engineers*, 3rd ed. Reading, Mass.: Addison Wesley Longman, 1999.
Young, Hugh D. and Roger A. Freedman, *Sears and Zemansky's University Physics*, 10th ed. Reading, Mass.: Addison Wesley Longman, 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 16-20, 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*	*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	5%	
1. Hydrostatic pressure	✓	
2. Buoyancy	✓	
3. Fluid flow continuity	✓	
4. Bernoulli's equation	✓	
B. Temperature and heat	3%	
1. Mechanical equivalent of heat	✓	
2. Specific and latent heat (including calorimetry)	✓	
3. Heat transfer and thermal expansion	✓	

Content Area	*Percentage Goals for Examinations* Physics B	Physics C
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)	✓	
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		✓

Content Area	*Percentage Goals for Examinations* *Physics B*	*Physics C*
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		℘
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	℘	

Content Area	*Percentage Goals for Examinations* Physics B	Physics C
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 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.

The 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 the next section. The green insert can be removed from the free-response answer booklet and used for reference when answering the free-response questions only.

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 should 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.

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. Additional information for students about study skills and test-taking strategies can be found in the AP Physics section of the College Board Web site (www.collegeboard.com/ap).

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 the College Board Web site along with scoring guidelines and some sample student responses.

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. 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.

***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.

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 2002 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.

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

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***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.

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 affects 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 does 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

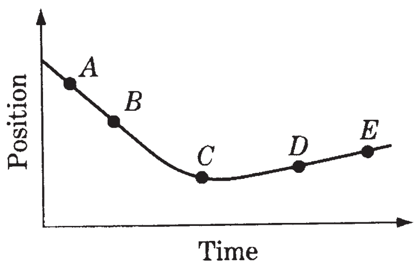
Most of the following sample questions, illustrative of the Physics B examination, have appeared in past examinations. The answers are on page 35.

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

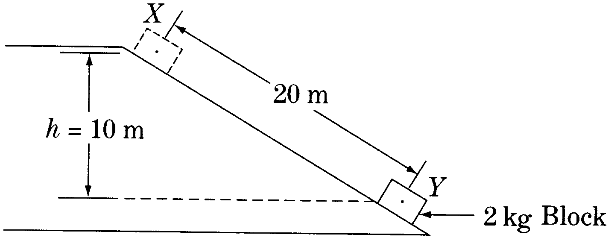
   (A) 3 s
   (B) 5 s
   (C) 6 s
   (D) 12 s
   (E) 25 s



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*

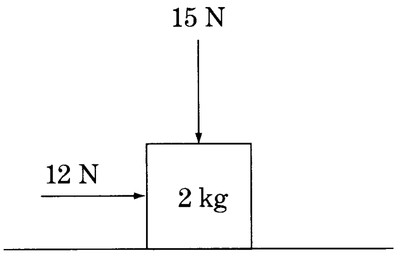
Questions 3-4



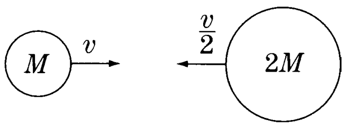
A 2 kg block, starting from rest, slides 20 m down a frictionless inclined plane from X to Y, dropping a vertical distance of 10 m as shown above.

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

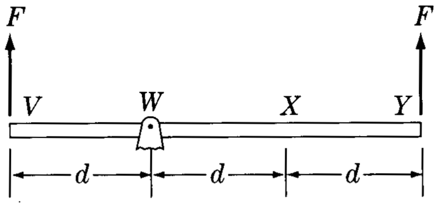
4. The speed of the block at point Y is most nearly
   (A) 7 m/s
   (B) 10 m/s
   (C) 14 m/s
   (D) 20 m/s
   (E) 100 m/s



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

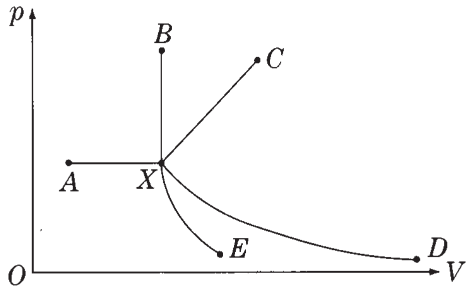


6. A ball of mass M and speed v collides head-on with a ball of mass $2M$ and speed $\frac{v}{2}$, as shown above. If the two balls stick together, their speed after the collision is
   (A) 0
   (B) $\frac{v}{2}$
   (C) $\frac{\sqrt{2}v}{2}$
   (D) $\frac{\sqrt{3}v}{2}$
   (E) $\frac{3v}{2}$



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.

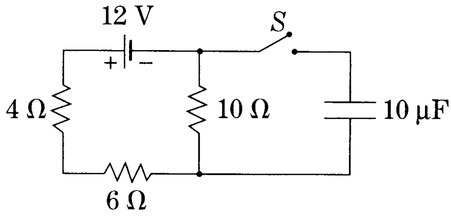


9. In the pV diagram above, the initial state of a gas is shown at point X. Which of the curves represents a process in which no work is done on or by the gas?
   (A) XA
   (B) XB
   (C) XC
   (D) XD
   (E) XE

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?

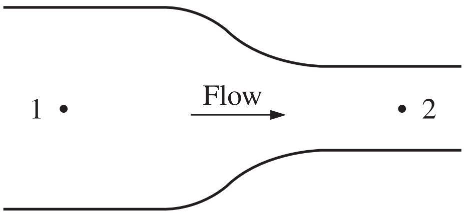
	Point P	Point T
(A)	Left	Right
(B)	Right	Left
(C)	Left	Toward the top of the page
(D)	Right	Toward the top of the page
(E)	Left	Toward the bottom of the page

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



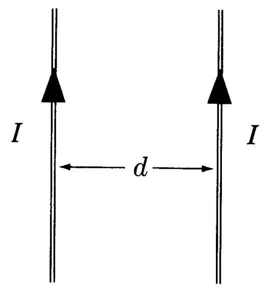
11. What is the current in the 4 | resistor while the switch S is open?
    (A) 0 A
    (B) 0.6 A
    (C) 1.2 A
    (D) 2.0 A
    (E) 3.0 A

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

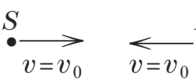
15. A source S of sound and a listener L each can be at rest or can move directly toward or away from each other with speed v_0. In which of the following situations will the observer hear the lowest frequency of sound from the source?

(A) 

(B) 

(C) 

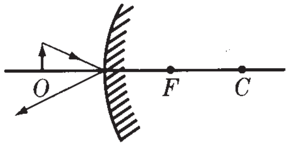
(D) 

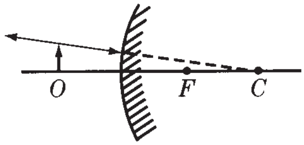
(E) 

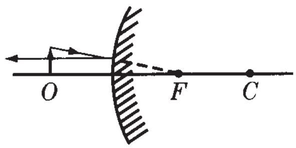
16. The wavelength of yellow sodium light in vacuum is 5.89×10^{-7} m. The speed of this light in glass with an index of refraction of 1.5 is most nearly

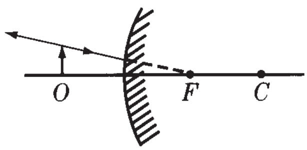
(A) 4×10^{-7} m/s
(B) 9×10^{-7} m/s
(C) 2×10^{8} m/s
(D) 3×10^{8} m/s
(E) 4×10^{8} m/s

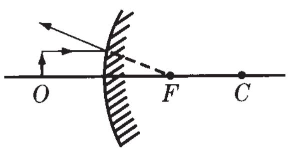
17. An object O is in front of a convex mirror. The focal point of the mirror is labeled F and the center of curvature is labeled C. The direction of the reflected ray is correctly illustrated in all of the following EXCEPT which diagram?

(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. A radioactive nucleus initially has Z protons and N neutrons. It emits a beta minus particle and then a gamma-ray photon. How many protons and neutrons does the remaining nucleus contain?

	Protons	Neutrons
(A)	$Z - 2$	$N - 2$
(B)	$Z - 1$	N
(C)	$Z - 1$	$N + 1$
(D)	Z	$N - 2$
(E)	$Z + 1$	$N - 1$

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 – E
4 – C	8 – C	12 – B	16 – C	20 – E

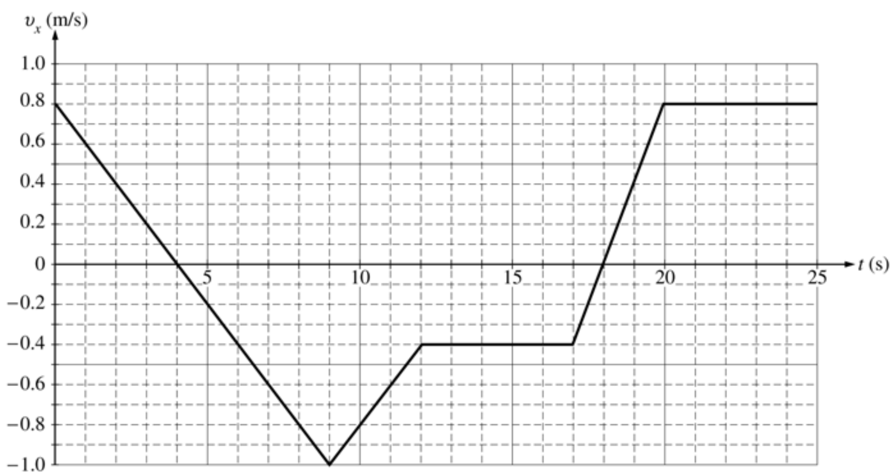
Physics B: Sample Free-Response Questions

The following seven questions constituted the complete free-response section of the 2000 Physics B Examination. Additional sample questions can be found in the AP section of the College Board Web site.

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.

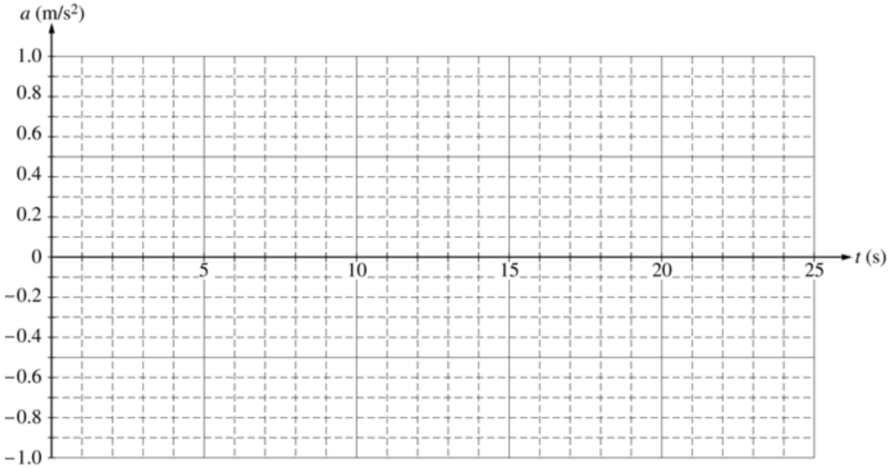
1. (15 points)

A 0.50 kg cart moves on a straight horizontal track. The graph of velocity v_x versus time t for the cart is given below.



(a) Indicate every time t for which the cart is at rest.
(b) Indicate every time interval for which the speed (magnitude of velocity) of the cart is increasing.
(c) Determine the horizontal position x of the cart at t = 9.0 s if the cart is located at x = 2.0 m at t = 0.

(d) On the axes below, sketch the acceleration a *versus* time t graph for the motion of the cart from $t = 0$ to $t = 25$ s.

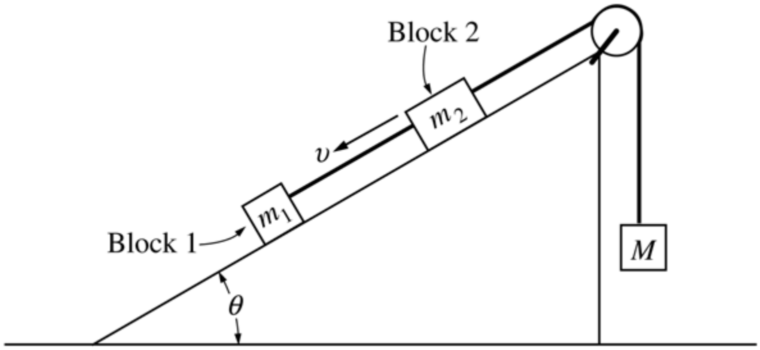


(e) From $t = 25$ s until the cart reaches the end of the track, the cart continues with constant horizontal velocity. The cart leaves the end of the track and hits the floor, which is 0.40 m below the track. Neglecting air resistance, determine each of the following.

i. The time from when the cart leaves the track until it first hits the floor

ii. The horizontal distance from the end of the track to the point at which the cart first hits the floor

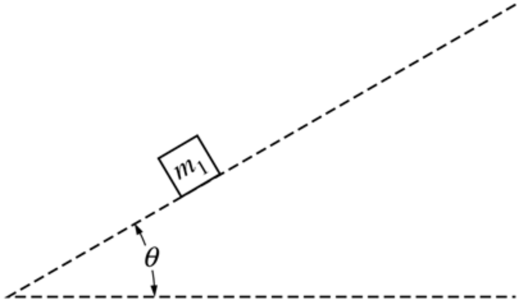
iii. The kinetic energy of the cart immediately before it hits the floor



2. (15 points)

Blocks 1 and 2 of masses m_1 and m_2, respectively, are connected by a light string, as shown above. These blocks are further connected to a block of mass M by another light string that passes over a pulley of negligible mass and friction. Blocks 1 and 2 move with a constant velocity υ down the inclined plane, which makes an angle θ with the horizontal. The kinetic frictional force on block 1 is f and that on block 2 is $2f$.

(a) On the figure below, draw and label all the forces on block m_1.

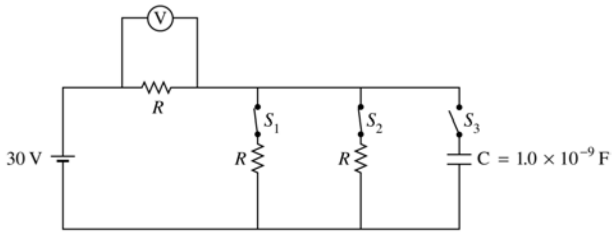


Express your answers to each of the following in terms of m_1, m_2, g, θ, and f.

(b) Determine the coefficient of kinetic friction between the inclined plane and block 1.

(c) Determine the value of the suspended mass M that allows blocks 1 and 2 to move with constant velocity down the plane.

(d) The string between blocks 1 and 2 is now cut. Determine the acceleration of block 1 while it is on the inclined plane.



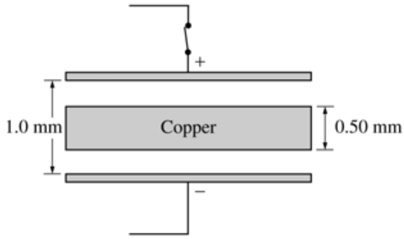
3. (15 points)

Three identical resistors, each with resistance R, and a capacitor of 1.0×10^{-9} F are connected to a 30 V battery with negligible internal resistance, as shown in the circuit diagram above. Switches S_1 and S_2 are initially closed, and switch S_3 is initially open. A voltmeter is connected as shown.

(a) Determine the reading on the voltmeter.

(b) Switches S_1 and S_2 are now opened, and then switch S_3 is closed. Determine the charge Q on the capacitor after S_3 has been closed for a very long time.

After the capacitor is fully charged, switches S_1 and S_2 remain open, switch S_3 remains closed, the plates are held fixed, and a conducting copper block is inserted midway between the plates, as shown below. The plates of the capacitor are separated by a distance of 1.0 mm, and the copper block has a thickness of 0.5 mm.



(c) i. What is the potential difference between the plates?

ii. What is the electric field inside the copper block?

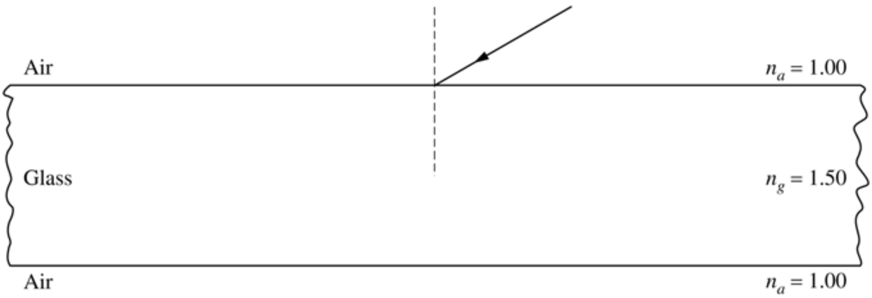
iii. On the diagram above, draw arrows to clearly indicate the direction of the electric field between the plates.

iv. Determine the magnitude of the electric field in each of the spaces between the plates and the copper block.

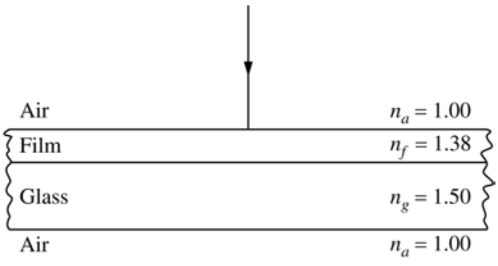
4. (15 points)

A sheet of glass has an index of refraction n_g = 1.50. Assume that the index of refraction for air is n_a = 1.00.

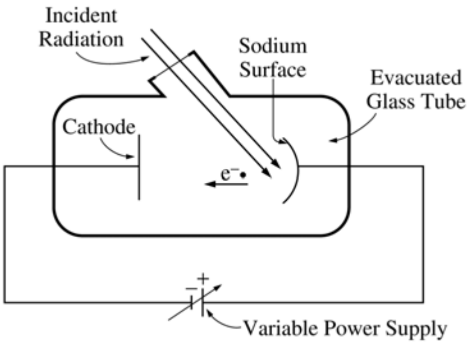
(a) Monochromatic light is incident on the glass sheet, as shown in the figure below, at an angle of incidence of 60°. On the figure, sketch the path the light takes the first time it strikes each of the two parallel surfaces. Calculate and label the size of each angle (in degrees) on the figure, including angles of incidence, reflection, and refraction at each of the two parallel surfaces shown.



(b) Next a thin film of material is to be tested on the glass sheet for use in making reflective coatings. The film has an index of refraction n_f = 1.38. White light is incident normal to the surface of the film as shown below. It is observed that at a point where the light is incident on the film, light reflected from the surface appears green (λ = 525 nm).



i. What is the frequency of the green light in air?
ii. What is the frequency of the green light in the film?
iii. What is the wavelength of the green light in the film?
iv. Calculate the minimum thickness of film that would produce this green reflection.



5. (10 points)

A sodium photoelectric surface with work function 2.3 eV is illuminated by electromagnetic radiation and emits electrons. The electrons travel toward a negatively charged cathode and complete the circuit shown above. The potential difference supplied by the power supply is increased, and when it reaches 4.5 V, no electrons reach the cathode.

(a) For the electrons emitted from the sodium surface, calculate the following.
   i. The maximum kinetic energy
   ii. The speed at this maximum kinetic energy

(b) Calculate the wavelength of the radiation that is incident on the sodium surface.

(c) Calculate the minimum frequency of light that will cause photoemission from this sodium surface.

6. (10 points)

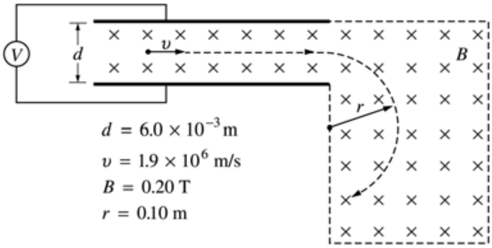
You are to design a procedure to determine experimentally the specific heat of an unknown liquid. You may not damage or destroy any equipment you use, and your method must be feasible and practical.

(a) List the equipment you would need. Include a labeled diagram.

(b) Describe the measurements you would make. Assign each measurement a symbol (such as time = t).

(c) Show explicitly using equations how the measured quantities would be used to determine the specific heat of the unknown liquid.

(d) Indicate one possible source of experimental error and discuss how it would affect your value for the specific heat. Justify your answer.



7. (10 points)

A particle with unknown mass and charge moves with constant speed $v = 1.9 \times 10^6$ m/s as it passes undeflected through a pair of parallel plates, as shown above. The plates are separated by a distance $d = 6.0 \times 10^{-3}$ m, and a constant potential difference V is maintained between them. A uniform magnetic field of magnitude $B = 0.20$ T directed into the page exists both between the plates and in a region to the right of them as shown. After the particle passes into the region to the right of the plates where only the magnetic field exists, its trajectory is circular with radius $r = 0.10$ m.

(a) What is the sign of the charge of the particle? Check the appropriate space below.

__ Positive __ Negative __ Neutral __ It cannot be determined from this information.

Justify your answer.

(b) On the diagram above, clearly indicate the direction of the electric field between the plates.

(c) Determine the magnitude of the potential difference V between the plates.

(d) Determine the ratio of the charge to the mass (q/m) of the particle.

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

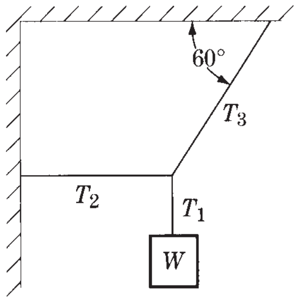
The speed v of an automobile moving on a straight road is given in meters per second as a function of time t in seconds by the following equation:

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

1. What is the acceleration of the automobile at $t = 2$ s?
   (A) 12 m/s²
   (B) 16 m/s²
   (C) 20 m/s²
   (D) 24 m/s²
   (E) 28 m/s²

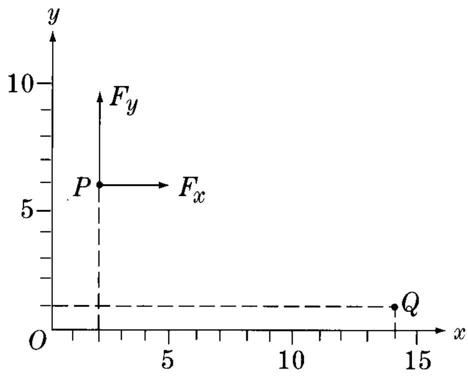
2. How far has the automobile traveled in the interval between $t = 0$ and $t = 2$ s?
   (A) 16 m
   (B) 20 m
   (C) 24 m
   (D) 32 m
   (E) 72 m

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



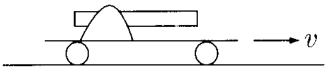
4. A system in equilibrium consists of an object of weight W that hangs from three ropes, as shown above. The tensions in the ropes are T_1, T_2, and T_3. Which of the following are correct values of T_2 and T_3?

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



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?

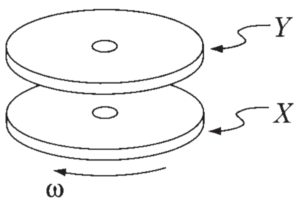
(A) $\frac{Mv}{m}$

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

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

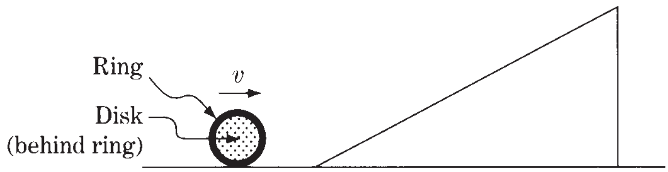
(D) $\frac{mv}{M}$

(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 2000 Physics C Examination. Additional sample questions can be found in the AP section of the College Board Web site.

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.

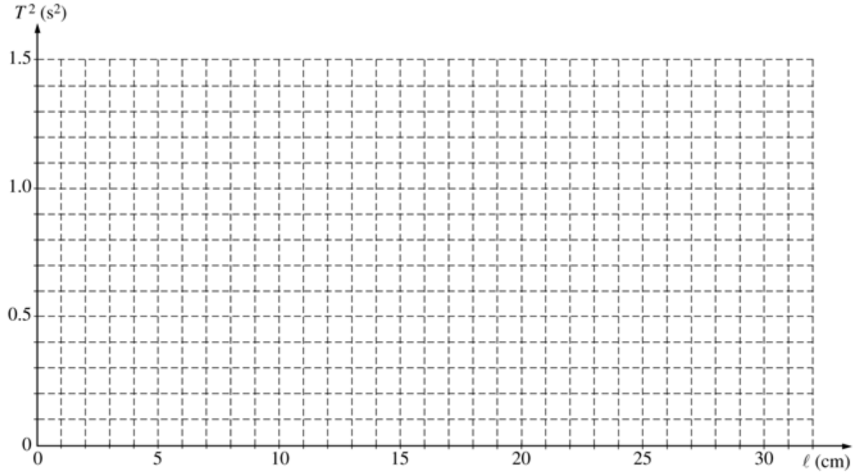
Mech 1.

You are conducting an experiment to measure the acceleration due to gravity g_u at an unknown location. In the measurement apparatus, a simple pendulum swings past a photogate located at the pendulum's lowest point, which records the time t_{10} for the pendulum to undergo 10 full oscillations. The pendulum consists of a sphere of mass m at the end of a string and has a length ℓ. There are four versions of this apparatus, each with a different length. All four are at the unknown location, and the data shown below are sent to you during the experiment.

ℓ (cm)	t_{10} (s)	T (s)	T^2 (s^2)
12	7.62		
18	8.89		
21	10.09		
32	12.08		

(a) For each pendulum, calculate the period T and the square of the period. Use a reasonable number of significant figures. Enter these results in the table above.

(b) On the axes below, plot the square of the period versus the length of the pendulum. Draw a best-fit straight line for this data.



(c) Assuming that each pendulum undergoes small amplitude oscillations, from your fit determine the experimental value g_{exp} of the acceleration due to gravity at this unknown location. Justify your answer.

(d) If the measurement apparatus allows a determination of g_u that is accurate to within 4%, is your experimental value in agreement with the value 9.80 m/s^2? Justify your answer.

(e) Someone informs you that the experimental apparatus is in fact near Earth's surface, but that the experiment has been conducted inside an elevator with a constant acceleration a. Assuming that your experimental value g_{exp} is exact, determine the magnitude and direction of the elevator's acceleration.

Mech 2.

A rubber ball of mass m is dropped from a cliff. As the ball falls, it is subject to air drag (a resistive force caused by the air). The drag force on the ball has magnitude bv^2, where b is a constant drag coefficient and v is the instantaneous speed of the ball. The drag coefficient b is directly proportional to the cross-sectional area of the ball and the density of the air and does not depend on the mass of the ball. As the ball falls, its speed approaches a constant value called the terminal speed.

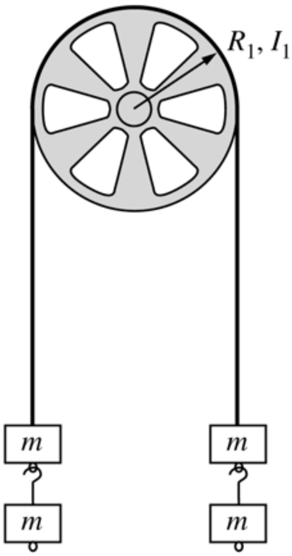
(a) On the figure below, draw and label all the forces on the ball at some instant before it reaches terminal speed.

(b) State whether the magnitude of the acceleration of the ball of mass m increases, decreases, or remains the same as the ball approaches terminal speed. Explain.

(c) Write, but do NOT solve, a differential equation for the instantaneous speed v of the ball in terms of time t, the given quantities, and fundamental constants.

(d) Determine the terminal speed v_t in terms of the given quantities and fundamental constants.

(e) Determine the energy dissipated by the drag force during the fall if the ball is released at height h and reaches its terminal speed before hitting the ground, in terms of the given quantities and fundamental constants.



Mech 3.

A pulley of radius R_1 and rotational inertia I_1 is mounted on an axle with negligible friction. A light cord passing over the pulley has two blocks of mass m attached to either end, as shown above. Assume that the cord does not slip on the pulley. Determine the answers to parts (a) and (b) in terms of m, R_1, I_1, and fundamental constants.

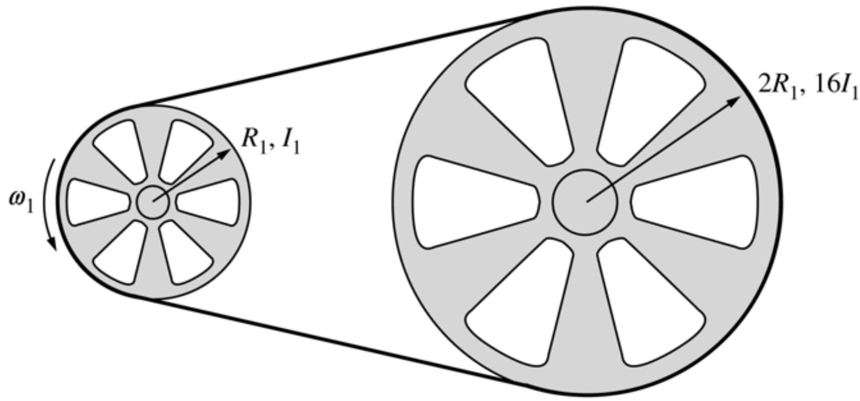
(a) Determine the tension T in the cord.

(b) One block is now removed from the right and hung on the left. When the system is released from rest, the three blocks on the left accelerate downward with an acceleration $\frac{g}{3}$. Determine the following.

i. The tension T_3 in the section of cord supporting the three blocks on the left

ii. The tension T_1 in the section of cord supporting the single block on the right

iii. The rotational inertia I_1 of the pulley



(c) The blocks are now removed and the cord is tied into a loop, which is passed around the original pulley and a second pulley of radius $2R_1$ and rotational inertia $16I_1$. The axis of the original pulley is attached to a motor that rotates it at angular speed ω_1, which in turn causes the larger pulley to rotate. The loop does not slip on the pulleys. Determine the following in terms of I_1, R_1, and ω_1.

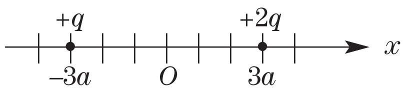
i. The angular speed ω_2 of the larger pulley
ii. The angular momentum L_2 of the larger pulley
iii. The total kinetic energy of the system

Physics C Electricity and Magnetism: Sample Multiple-Choice Questions

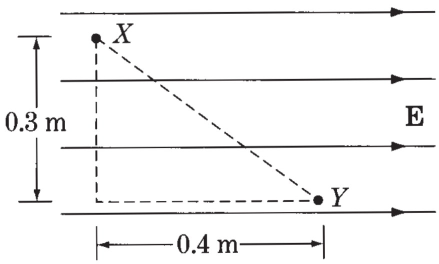
Most of the following sample questions, illustrative of the Physics C Electricity and Magnetism examination, have appeared in past examinations. The answers are on page 61.

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.



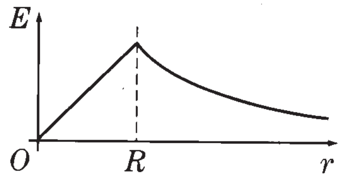
1. Two charges are located on the x-axis of a coordinate system as shown above. The charge $+2q$ is located at $x = +3a$ and the charge $+q$ is located at $x = -3a$. Where on the x-axis should an additional charge $+4q$ be located to produce an electric field equal to zero at the origin O?
   (A) $x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



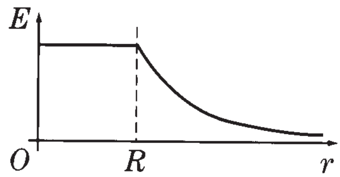
2. A uniform electric field **E** of magnitude 6,000 V/m exists in a region of space as shown above. What is the electric potential difference, $V_X - V_Y$, between points X and Y?
(A) –12,000 V
(B) 0 V
(C) 1,800 V
(D) 2,400 V
(E) 3,000 V

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?

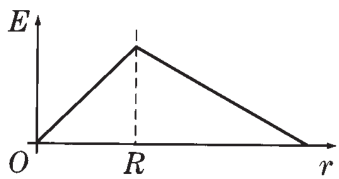
(A)



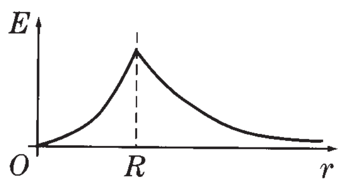
(B)



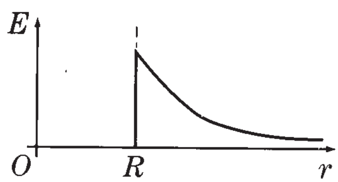
(C)

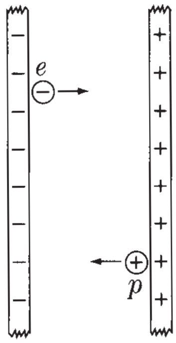


(D)

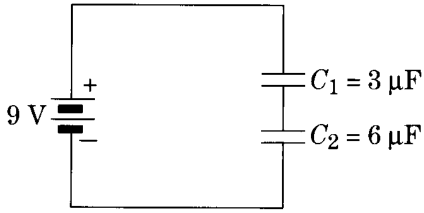


(E)

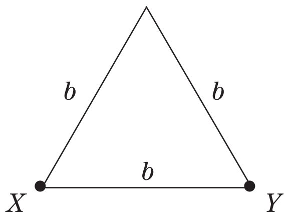




4. A proton p and an electron e are released simultaneously on opposite sides of an evacuated area between large, charged parallel plates, as shown above. Each particle is accelerated toward the oppositely charged plate. The particles are far enough apart so that they do not affect each other. Which 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) $\frac{3}{2}\frac{A}{\rho b}$

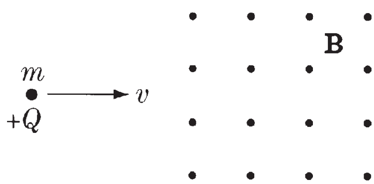
(B) $3\frac{A}{\rho b}$

(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.

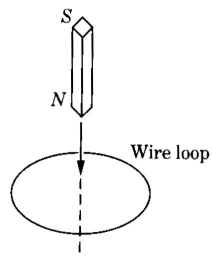
7. Which of the following best indicates the magnitude and the direction of the magnetic force **F** on the charge just after the charge enters the magnetic field?

	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

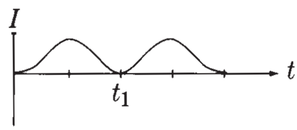
8. If the magnetic field strength is increased, which of the following will be true about the radius R?

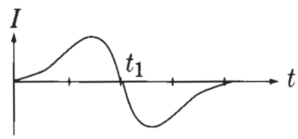
I. R increases if the incident speed is held constant.
II. For R to remain constant, the incident speed must be increased.
III. For R to remain constant, the incident speed must be decreased.

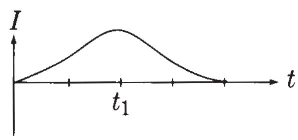
(A) I only
(B) II only
(C) III only
(D) I and II only
(E) I and III only

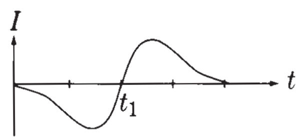


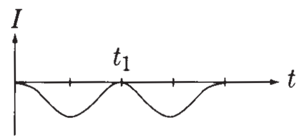
9. A bar magnet is lowered at constant speed through a loop of wire as shown in the diagram above. The time at which the midpoint of the bar magnet passes through the loop is t_1. Which of the following graphs best represents the time dependence of the induced current in the loop? (A positive current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

(A)


(B)


(C)


(D)


(E)


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

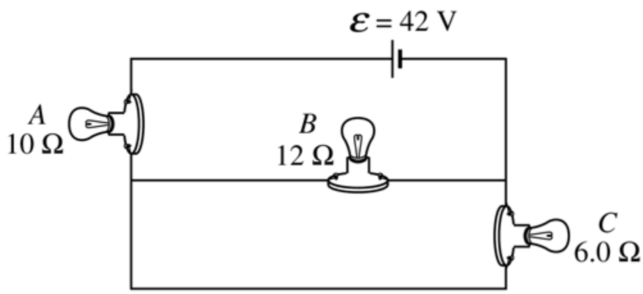
Answers to Physics C Electricity and Magnetism Multiple-Choice Questions

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 2000 Physics C examination. Additional sample questions can be found in the AP section of the College Board Web site.

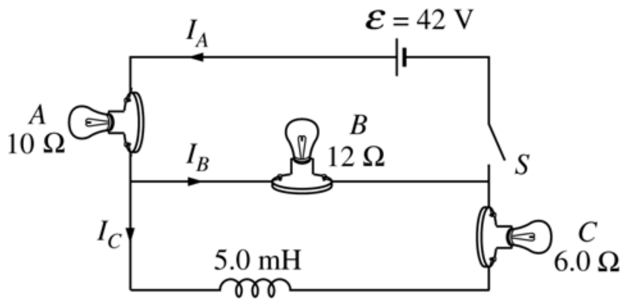
Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part, NOT in the green insert.



E & M 1.

Lightbulbs *A*, *B*, and *C* are connected in the circuit shown above.

(a) List the bulbs in order of their brightness, from brightest to least bright. If any bulbs have the same brightness, state which ones. Justify your answer.



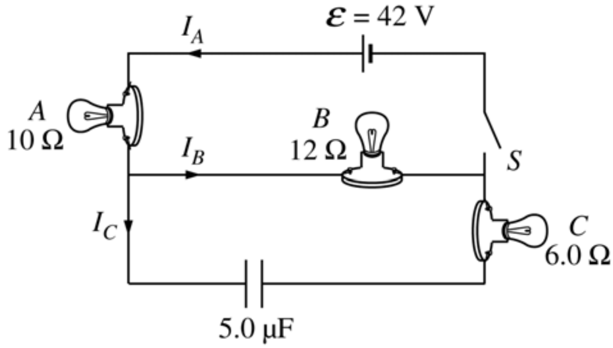
Now a switch S and a 5.0 mH inductor are added to the circuit, as shown above. The switch is closed at time $t = 0$.

(b) Determine the currents I_A, I_B, and I_C for the following times.

i. Immediately after the switch is closed

ii. A long time after the switch is closed

(c) On the axes below, sketch the magnitude of the potential difference V_L across the inductor as a function of time, from immediately after the switch is closed until a long time after the switch is closed.



(d) Now consider a similar circuit with an uncharged 5.0 μF capacitor instead of the inductor, as shown above. The switch is again closed at time $t = 0$. On the axes below, sketch the magnitude of the potential difference V_{cap} across the capacitor as a function of time, from immediately after the switch is closed until a long time after the switch is closed.

E & M 2.

Three particles, A, B, and C, have equal positive charges Q and are held in place at the vertices of an equilateral triangle with sides of length ℓ, as shown in the figures below. The dotted lines represent the bisectors for each side. The base of the triangle lies on the x-axis, and the altitude of the triangle lies on the y-axis.

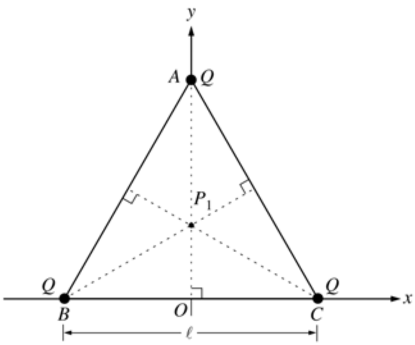


Figure 1

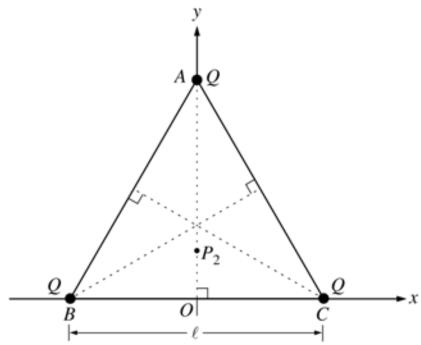


Figure 2

(a)

i. Point P_1, the intersection of the three bisectors, locates the geometric center of the triangle and is one point where the electric field is zero. On Figure 1 above, draw the electric field vectors $\mathbf{E}_A$, $\mathbf{E}_B$, and $\mathbf{E}_C$ at P_1 due to each of the three charges. Be sure your arrows are drawn to reflect the relative magnitude of the fields.

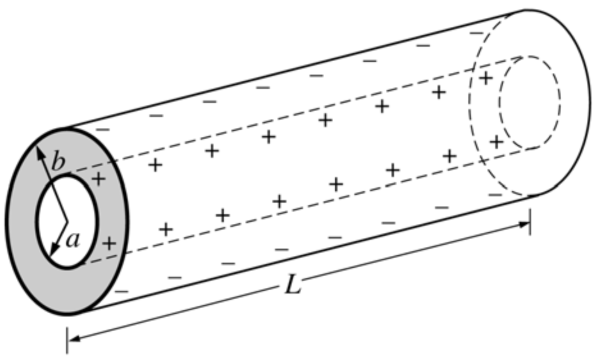
ii. Another point where the electric field is zero is point P_2 at $(0, y_2)$. On Figure 2 above, draw electric field vectors $\mathbf{E}_A$, $\mathbf{E}_B$, and $\mathbf{E}_C$ at P_2 due to each of the three point charges. Indicate below whether the magnitude of each of these vectors is greater than, less than, or the same as for point P_1.

	Greater than at P_1	Less than at P_1	The same as at P_1
E_A			
E_B			
E_C			

(b) Explain why the x-component of the total electric field is zero at any point on the y-axis.

(c) Write a general expression for the electric potential V at any point on the y-axis inside the triangle in terms of Q, ℓ, and y.

(d) Describe how the answer to part (c) could be used to determine the y-coordinates of points P_1 and P_2 at which the electric field is zero. (You do not need to actually determine these coordinates.)



E & M 3.

A capacitor consists of two conducting, coaxial, cylindrical shells of radius a and b, respectively, and length $L >> b$. The space between the cylinders is filled with oil that has a dielectric constant K. Initially both cylinders are uncharged, but then a battery is used to charge the capacitor, leaving a charge $+Q$ on the inner cylinder and $-Q$ on the outer cylinder, as shown above. Let r be the radial distance from the axis of the capacitor.

(a) Using Gauss's law, determine the electric field midway along the length of the cylinder for the following values of r, in terms of the given quantities and fundamental constants. Assume end effects are negligible.

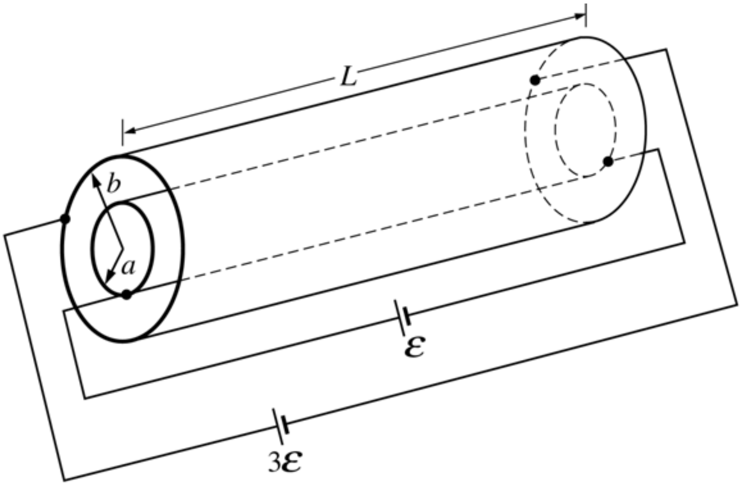
i. $a < r < b$

ii. $b < r << L$

(b) Determine the following in terms of the given quantities and fundamental constants.

i. The potential difference across the capacitor

ii. The capacitance of this capacitor



(c) Now the capacitor is discharged and the oil is drained from it. As shown above, a battery of emf $\mathcal{E}$ is connected to opposite ends of the inner cylinder and a battery of emf $3\mathcal{E}$ is connected to opposite ends of the outer cylinder. Each cylinder has resistance R. Assume that end effects and the contributions to the magnetic field from the wires are negligible. Using Ampere's law, determine the magnitude B of the magnetic field midway along the length of the cylinders due to the current in the cylinders for the following values of r.

i. $a < r < b$

ii. $b < r << L$

AP Program Essentials

The AP Reading

In June, the free-response sections of the exams, as well as the portfolios in Studio Art, are scored by college and secondary school teachers at the AP Reading. Thousands of these faculty consultants participate, under the direction of a Chief Faculty Consultant 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 member of a college faculty and would like to serve as a faculty consultant, you can apply online in the AP section of the College Board's Web site. Alternatively, send an e-mail message to apreader@ets.org, or call Performance Scoring Services at 609 406-5383.

AP Grades

The faculty consultants' judgments 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 in the subject pages of the AP Web site, as is information on how the cut-off points for each AP grade are calculated.

AP and College Credit

Advanced placement and/or credit is 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 Give Credit for AP Grades

Colleges need to know that the AP grades they receive for 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 are compared, 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 their 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 the AP pages of the College Board's Web site. (The aforementioned Morgan and Ramist study can be downloaded from the site in its entirety.)

Guidelines on Granting Credit for AP Grades

If you are an admission administrator and need guidance on setting a policy for your college, 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 Regional Office, as noted on the inside back cover of this booklet.

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, though, that policies are subject to change. Contact the college directly to get the most up-to-date information.

AP Scholar Awards and the AP International Diploma

The AP Program offers a number of awards to recognize high school students who have demonstrated college-level achievement through AP courses and exams. In addition, the AP International Diploma (APID) certifies the achievement of successful AP candidates who plan to apply to a university outside the United States.

For detailed information on AP Scholar Awards and the APID, including qualification criteria, visit the AP Web site or contact the College Board's National Office. Students' questions are also answered in the *AP Bulletin for Students and Parents*; information about ordering and downloading the *Bulletin* can be found at the back of this booklet.

AP Calendar

To get an idea of the various events associated with running an AP program and administering the AP Exams, please refer to this year's edition of *A Guide to the Advanced Placement Program*; information about ordering and downloading the *Guide* can be found at the back of this booklet.

Test Security

The entire AP Exam must be kept secure until the scheduled administration date. Except during the actual exam administration, exam materials must be placed in locked storage. Forty-eight hours after the exam has been administered, the green and blue inserts from the free-response section (Section II) are 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 candidates taking

*The alternate (make-up) form of the free-response section is NOT released.

the exam can ever have access to or see the questions contained in this section — this includes AP Coordinators and AP teachers. The multiple-choice section must never be shared or copied in any manner.

Various combinations of 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 only be attained 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 chance to perform 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*.** The manual also includes directions on how to deal with misconduct and other security problems. Any breach of security should be reported immediately through the test security hot line (call 800 353-8570, e-mail tsreturns@ets.org, or fax 609 406-9709).

Teacher Support

Look for these enhanced Web resources at www.collegeboard.com/ap

- Information about AP Exam development, administration, scoring and grading, fees, and scheduling.
- Program news, such as exam format changes, opinion polls (teacher surveys, ad hoc polls), and profiles of successful teachers and AP programs.
- A searchable catalog of teaching resources, including: course topic outlines, sample syllabi and lesson plans, strategies and tips, topic briefs, links, and textbook reviews.
- A searchable catalog of professional development opportunities (e.g., workshops, summer institutes, conferences). New and experienced AP teachers are invited to attend workshops and institutes to learn the fundamentals of teaching an AP course, as well as the latest expectations for each course and exam. Sessions ranging from one day to three weeks in length are held year-round. Dates, locations, topics, and fee information are also available through the College Board's Regional Offices.

- Online forums for exchanging ideas with AP teachers.
- Sample multiple-choice and free-response questions.

To supplement these online resources, there are a number of AP publications, CD-ROMs, and videos that can assist AP teachers. Please see the following pages for an overview and for ordering information.

Pre-AP™

Preparing Students for Challenging Courses; Preparing Teachers for Student Success

Pre-AP has two objectives: (1) to promote access to AP for all students; (2) to provide professional development through content-specific strategies to build a rigorous curriculum. Teachers employ Pre-AP strategies and materials to introduce skills, concepts, and assessment methods that prepare students for success when they take AP and other challenging academic courses. Schools use Pre-AP strategies to strengthen and align the curriculum across grade levels, and to increase the academic challenge for all students.

Pre-AP professional development is available to teachers through Building Success workshops and through AP Vertical Teams™ conferences and workshops.

- **Building Success** is a two-day workshop that assists English and history teachers in designing curricula for grade 7 and above. Teachers learn strategies to help students engage in active questioning, analysis, and constructing arguments. Workshop topics include assessment, interdisciplinary teaching and learning, and vertical planning.
- **AP Vertical Teams** are trained via one-day workshops, two-day conferences, and five-day summer institutes; they enable middle school and high school teachers to prepare Pre-AP students for academic success in AP courses and in college. Topics include organizing effective teams, aligning curricula, and developing content-specific teaching strategies.
- **Setting the Cornerstones: Building the Foundation of AP Vertical Teams** is a two-day workshop designed to provide information about the College Board and the AP Program, and to suggest strategies for establishing coherence, commitment, collegiality, and collaboration among the members of an AP Vertical Team.

For more information about Building Success workshops and for schedules of AP Vertical Teams workshops and conferences, contact your College Board Regional Office. Alternatively, contact Mondy Raibon, Pre-AP Initiatives, AP Program, The College Board, 45 Columbus Avenue, New York, NY 10023-6992; 212 713-8156; mraibon@collegeboard.org.

AP Publications and Other Resources

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

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

Ordering Information

You have several options for ordering publications:

- **Online.** Visit the College Board store to see descriptions and pictures of AP publications and to place your order.
- **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 the AP Library (www.collegeboard.com/ap/library).
- **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., and Saturday 9:00 a.m. to 4:45 p.m. ET. Have your American Express, 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 fourth-class book rate postage (or its equivalent) on all prepaid orders; you should allow two to three weeks for delivery. Postage will be charged on all orders requiring billing and/or requesting a faster method of shipment.

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

Print

Items marked with a computer mouse icon can be downloaded for free from the AP Library (www.collegeboard.com/ap/library).

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

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

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

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

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

Course Descriptions provide an outline of the AP course content, explain the kinds of skills students are expected to demonstrate in the corresponding introductory college-level course, and describe the AP Exam. They also provide sample multiple-choice questions with an answer key, as well as sample free-response questions. A complete set of Course Descriptions is available for $100.

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

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

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

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

Pre-AP: Achieving Equity, Emphasizing Excellence: Free **A, T**

An informational brochure describing the Pre-AP concept and outlining the characteristics of a successful Pre-AP program.

Released Exams: $20
($30 for "double" subjects: Calculus, Computer Science, Latin, Physics) **T**

About every four years, on a staggered 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 standards, and commentary that explains why the responses received the scores they did.

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

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

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

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

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

Teacher's Guides: $12 **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 recommended teaching resources.

AP Vertical Team Guides **T, A**

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

Multimedia

EssayPrep® **SP, T**

EssayPrep is available through the AP subject pages of the College Board's Web site. Students can select an essay topic, type a response, and get an evaluation from an experienced reader. The service is offered for the free-response portions of the AP Biology, English Language and Composition, English Literature and Composition, and U.S. History Exams. The fee is $15 per response for each evaluation. SAT® II: Writing Subject Test topics are also offered for a fee of $10. Multiple evaluations can be purchased at a 10–20% discount.

APCD®: $49 (home version),
$450 (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.

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

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

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

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

College Board Regional 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
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215 387-7600
E-mail: msro@collegeboard.org

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Robert DiYanni/Theresa Chang-whei Jen/Bernadette Longboy
45 Columbus Avenue, New York, NY 10023-6992
212 713-8091
E-mail: chensley@collegeboard.org

2002-03 Physics Development Committee and Chief Faculty Consultant

Gay B. Stewart, University of Arkansas, Fayetteville, Arkansas, *Chair*
Laurence S. Cain, Davidson College, Davidson, North Carolina
Stephen E. Eshleman, Upper Darby High School District, Drexel Hill, Pennsylvania
Hasan Fakhruddin, The Indiana Academy for Science, Math & Humanities, Muncie, Indiana
Joseph A. Keane, St. Thomas Aquinas College, Sparkill, New York
Martha L. Lietz, Niles West High School, Skokie, Illinois
Chief Faculty Consultant: **J. Patrick Polley**, Beloit College, Beloit, Wisconsin
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