CollegeBoard AP

PHYSICS

PHYSICS B
PHYSICS C
Course Description

MAY 2006, MAY 2007

The College Board: Connecting Students to College Success

The College Board is a not-for-profit membership association whose mission is to connect students to college success and opportunity. Founded in 1900, the association is composed of more than 4,700 schools, colleges, universities, and other educational organizations. Each year, the College Board serves over three and a half million students and their parents, 23,000 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 excellence and equity, and that commitment is embodied in all of its programs, services, activities, and concerns.

For further information, visit www.collegeboard.com.

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

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Dear Colleagues:

In 2004, nearly 15,000 schools offered high school students the opportunity to take AP® courses, and over 1.1 million students then took the challenging AP Exams. These students felt the power of learning come alive in the classroom, and many earned college credit and placement while still in high school. Behind these students were talented, hardworking teachers who are the heart and soul of the Advanced Placement Program®.

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

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

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

Sincerely,

Gaston Caperton
President
The College Board

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Welcome to the AP® Program

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

Most colleges and universities in the United States, as well as colleges and universities in more than 30 other countries, have an AP policy granting incoming students credit, placement, or both on the basis of their AP Exam grades. Many of these institutions grant up to a full year of college credit (sophomore standing) to students who earn a sufficient number of qualifying AP grades.

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

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

AP Courses

Thirty-eight AP courses in a wide variety of subject areas are available now or are under development. A committee of college faculty and master AP teachers designs each AP course to cover the information, skills, and assignments found in the corresponding college course. See page 2 for a complete list of AP courses and exams.

AP Exams

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

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

AP Courses and Exams

Art
Art History
Studio Art: 2-D Design
Studio Art: 3-D Design
Studio Art: Drawing

Biology

Calculus
Calculus AB
Calculus BC

Chemistry

Chinese Language and Culture (2006-07)

Computer Science
Computer Science A
Computer Science AB

Economics
Macroeconomics
Microeconomics

English
English Language and Composition
English Literature and Composition

Environmental Science

French
French Language
French Literature

German Language

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

History
European History
United States History
World History

Human Geography

Italian Language and Culture (2005-06)

Japanese Language and Culture (2006-07)

Latin
Latin Literature
Latin: Vergil

Music Theory

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

Psychology

Russian Language and Culture (Date to be determined)

Spanish
Spanish Language
Spanish Literature

Statistics

AP Physics

Introduction

What We Are About: A Message from the Development Committee

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

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

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

The AP Physics Exams 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 exams 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 exams that promote excellent and appropriate instruction in physics.

The Courses

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

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

In the achievement of these goals, concentration on basic principles of physics and their applications through careful and selective treatment of well-chosen areas is more important than superficial and encyclopedic coverage of many detailed topics. Within the general framework outlined on pages 15–18, teachers may exercise some freedom in the choice of topics.

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

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

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

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

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

The AP Physics C course is intended to be equivalent to part of a *Category C* sequence and covers two major areas: mechanics, and electricity and magnetism, with equal emphasis on both.

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 Exams, other college admission information, or a college-administered exam. The AP Exams are not designed to grant credit or exemption for such high-level courses but may facilitate admission to them.

Course Selection

It is important for those teaching and advising AP students to consider the relation of AP courses to a student's college plans. In some circumstances it is advantageous to take the AP Physics B course. The student may be interested in studying physics as a basis for more advanced work in the life sciences, medicine, geology, and related areas, or as a component in a 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 AP Calculus.

There are two separate AP Physics Exams, Physics B and Physics C. Students take one exam or the other. Both exams contain multiple-choice and free-response questions. The Physics B Exam 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 Exam covers topics in mechanics, electricity and magnetism, fluid mechanics and thermal physics, waves and optics, and atomic and nuclear physics; a single exam grade is reported. Similarly, the Physics C Exam corresponds to the Physics C course. One part of the Physics C Exam covers mechanics; the other part covers electricity and magnetism. Students are permitted to take either or both parts of this exam, 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 exams 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 *AP Physics Teacher's Guide.* This publication includes practical advice from successful AP teachers. The *2004 AP Physics B and Physics C Released Exams* book contains the complete exams, with solutions and grading standards for the free-response sections and sample student responses, as well as statistical data on student performance. For information about ordering these publications and others, see pages 71–72. Additional useful information may be found at AP Central (apcentral.collegeboard.com).

Instructional Approaches

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

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

If AP Physics is taught as a second-year course, it is recommended that the course meet for at least 250 minutes per week (the equivalent of a 50-minute period every day). However, if it is to be taught as a first-year course, approximately 90 minutes per day (450 minutes per week) is recommended in order to devote sufficient time to study the material to an appropriate depth and allow time for labs.

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

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

Laboratory

Importance and Rationale

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

- design experiments;
- observe and measure real phenomena;
- organize, display, and critically analyze data;
- analyze sources of error and 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.

Laboratory experience is also important in helping students understand the topics being considered. Thus it is valuable to ask students to write informally about what they have done, observed, and concluded, as well as for them to keep well-organized laboratory notebooks.

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.

Some questions or parts of questions on each AP Physics Exam deal with lab-related skills, such as design of experiments, data analysis, and error analysis, and may distinguish between students who have had laboratory experience and those who have not. In addition, understanding gained in the laboratory may improve students' test performance overall.

Implementation and Recommendations

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

In addition to equipment commonly included in college labs, 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 so that students 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 recommended for many labs. It is not advisable to attempt to complete high-quality AP laboratory work only within standard 45- to 50-minute periods.**

If AP Physics is taught as a second-year physics course, 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.

Past surveys of introductory college physics courses, both noncalculus and calculus-based, have revealed that on average about 20 percent of the total course credit awarded can be attributed to lab performance; from two to three hours per week are typically 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 colleges. Also, college faculty have reported that some lab time occasionally may be used for other purposes. 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.

Laboratory activities in colleges and AP courses can involve different levels of student involvement. They can generally be classified as: (1) prescribed or "cookbook," (2) limited investigations with some direction provided, and (3) open investigations with little or no direction provided. While many college professors believe that labs in the latter two categories 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.

In past surveys, colleges have cited use of the following techniques to assess student lab performance: lab reports, direct observation, written tests designed specifically for lab, lab-related questions on regular lecture tests, lab practical exams, and maintenance of lab notebooks. When the colleges assessed laboratory skills with written test questions, they reported attempting to assess the following skills in order of decreasing frequency: analysis of data, analysis of errors, design of experiments, and evaluation of experiments and suggestions for future investigations.

A more detailed laboratory guide is available and can be ordered through AP Central. This guide contains descriptions of a number of experiments that typify the type and level of skills that should be developed by AP students in conducting laboratory investigation. The experiments are not mandatory; they can be modified or similar experiments substituted as long as they assist the student in developing these skills. Each edition of the *AP Physics Teacher's Guide* also provides additional suggestions for the laboratory. The guide mentions specific experiments that other AP teachers have tried and liked and lists publications and other sources of information that may provide additional ideas for low-cost experiments. It will 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, as an adjunct to their AP grades, can be very useful to students if they desire credit for or exemption from an introductory college course that includes a laboratory. Although colleges can expect that most entering AP students have been exposed to many of the same laboratory experiments performed by their own introductory students, individual consultation with students is often used to help determine the nature of their laboratory experience.

Physics B

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

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

Cutnell, John D., and Kenneth W. Johnson. 2004. *Physics*, 6th ed. Hoboken, N.J.: John Wiley & Sons.

Giancoli, Douglas C. 2005. *Physics: Principles with Applications.* 6th ed. Upper Saddle River, N.J.: Prentice Hall.

Hecht, Eugene. 2003. *Physics: Algebra/Trigonometry.* 3rd ed. Pacific Grove, Calif.: Brooks/Cole Publishing.

Serway, Raymond A., and Jerry S. Faughn. 2003. *College Physics.* 6th ed. Pacific Grove, Calif.: Brooks/Cole Publishing.

Wilson, Jerry D., and Anthony J. Buffa. 2003. *College Physics.* 5th ed. Upper Saddle River, N.J.: Prentice Hall.

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 15–18 for coverage of five general areas: Newtonian mechanics, fluid mechanics and thermal physics, electricity and magnetism, waves and optics, and atomic and nuclear physics.

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 Exams have been given.

Physics C

In the typical Physics 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.

Chabay, Ruth W., and Bruce A. Sherwood. 2003. *Matter & Interaction II: Electric & Magnetic Interactions*, *Version 1.2.* Hoboken, N.J.: John Wiley & Sons.

Fishbane, Paul M., Stephen Gasiorowicz, and Stephen T. Thornton. 2005. *Physics for Scientists and Engineers.* 3rd ed. Upper Saddle River, N.J.: Prentice Hall.

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

Halliday, David, Robert Resnick, and Jearl Walke. 2005. *Fundamentals of Physics.* 7th ed. Hoboken, N.J.: John Wiley & Sons.

Halliday, David, Robert Resnick, and Kenneth Krane. 2001. *Physics*, *Parts I and II.* 5th ed. Hoboken, N.J.: John Wiley & Sons.

Knight, Randall D. 2004. *Physics for Scientists and Engineers: A Strategic Approach with Modern Physics.* Boston: Addison-Wesley.

Serway, Raymond A., Robert J. Beichner and John J. Jewett. 2000. *Physics for Scientists and Engineers.* 5th ed. Pacific Grove, Calif.: Brooks/Cole Publishing.

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

Tipler, Paul A. and Gene P. Mosca. 2004. *Physics for Scientists and Engineers.* 5th ed. New York: W.H. Freeman.

Wolfson, Richard, and Jay M. Pasachoff. 1999. *Physics for Scientists and Engineers.* 3rd ed. Boston: Addison-Wesley.

Young, Hugh D. and Roger A. Freedman. 2004. *University Physics.* 11th ed. Boston: Addison-Wesley.

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 exam. 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 Exams 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 exams, 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 15–18, and for each category the percentage goals for each exam 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 exam. Questions for the exam will come from these subtopics, but not all of the subtopics will necessarily be included in every exam, 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.

A more detailed topic outline is contained in the "Learning Objectives for Advanced Placement Physics," which can be found on AP Central.

Content Outline for Physics B and Physics C

> Some changes have been made to the descriptions and organization of the Content Outline so it better aligns with the published "Learning Objectives." However, the content of the courses and exams has not changed.

Content Area	*Percentage Goals for Exams* *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	9%	10%
1. Static equilibrium (first law)	√	√
2. Dynamics of a single particle (second law)	√	√
3. Systems of two or more objects (third law)	√	√
C. Work, energy, power	5%	7%
1. Work and work–energy theorem	√	√
2. 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 Exams* *Physics B*	*Physics C*
E. Circular motion and rotation	4%	9%
1. Uniform circular motion	√	√
2. Torque and rotational statics	√	√
3. Rotational kinematics and dynamics		√
4. Angular momentum and its conservation		√
F. Oscillations and gravitation	6%	9%
1. Simple harmonic motion (dynamics and energy relationships)	√	√
2. Mass on a spring	√	√
3. Pendulum and other oscillations	√	√
4. Newton's law of gravity	√	√
5. Orbits of planets and satellites		
a. Circular	√	√
b. General		√
II. Fluid Mechanics and Thermal Physics	15%	
A. Fluid Mechanics	6%	
1. Hydrostatic pressure	√	
2. Buoyancy	√	
3. Fluid flow continuity	√	
4. Bernoulli's equation	√	
B. Temperature and heat	2%	
1. Mechanical equivalent of heat	√	
2. Heat transfer and thermal expansion	√	
C. Kinetic theory and thermodynamics	7%	
1. Ideal gases		
a. Kinetic model	√	
b. Ideal gas law	√	
2. Laws of thermodynamics		
a. First law (including processes on pV diagrams)	√	
b. Second law (including heat engines)	√	

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

Content Area	Percentage Goals for Exams: Physics B	Physics C
IV. Waves and Optics	15%	
A. Wave motion (including sound)	5%	
1. Traveling waves	√	
2. Wave propagation	√	
3. Standing waves	√	
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, the photoelectric effect, Compton scattering, x-rays	√	
2. Atomic energy levels	√	
3. Wave-particle duality	√	
B. Nuclear physics	3%	
1. Nuclear reactions (including conservation of mass number and charge)	√	
2. Mass–energy equivalence	√	

Laboratory and experimental situations: Each exam 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 exam 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 Exams

The AP Physics B Exam is 3 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 Exam.

The free-response section will usually contain 6 or 7 questions. Examples of possible formats are 2 questions of about 17 minutes each and 5 shorter questions of about 11 minutes each, or 4 questions of about 17 minutes each and 2 shorter questions of about 11 minutes each. However, future exams might include a combination of questions of other lengths.

The AP Physics C Exam consists of two parts, each 1 hour and 30 minutes 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 3 questions, each taking about 15 minutes. However, future exams might include a larger number of shorter questions.

The percentages of each exam 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 exam 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 exams 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; or
- 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 exam 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 exam 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 exams. The equation tables are described in greater detail in a later section. The green insert can be removed from the free-response answer booklet and used for reference when answering the free-response questions only.

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

Since the complete exams are intended to provide the maximum information about differences in students' achievement in physics, students may find them more difficult than many classroom exams. The best way for teachers to familiarize their students with the level of difficulty is to give them actual released exams (both multiple-choice and free-response sections) from past administrations. Information about ordering publications is on pages 69–73. Recent free-response sections can also be downloaded from AP Central along with scoring guidelines and some sample student responses.

The Free-Response Sections—Student Presentation

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

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

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

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

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

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

Calculators and Equation Tables

Policies regarding the use of calculators on the exams 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 exams 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 <u>multiple-choice sections</u> of the Physics B and Physics C exams. 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.

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*__Exceptions to calculator use.__ Calculators that are not permitted are PowerBooks and portable/handheld computers; electronic writing pads or pen-input/stylus-driven devices (e.g., Palm, PDAs, Casio ClassPad 300); pocket organizers; models with QWERTY (i.e., typewriter) keypads (e.g., TI-92 Plus, Voyage 200); models with paper tapes; models that make noise or "talk"; models that require an electrical outlet; cell phone calculators. Students may not share calculators.

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

Calculators are allowed on the <u>free-response section</u> of both exams. Any programmable or graphing calculator may be used except as noted on page 22,* and students will <u>not be required to erase their calculator memories</u> before and after the exam. 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 exams are designed and scored 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 exam 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 2006 and 2007 exams are included as an insert in this book 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 exam 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 scoring 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 exams. However, they do not include all equations that might possibly be used. For example, they do not include many equations that can be derived by combining others in the tables. Nor do they include equations that are simply special cases of any that are in the tables. Students are responsible for understanding the physical principles that underlie each equation and for knowing the conditions for which each equation is applicable.

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

In summary, the purpose of minimizing numerical calculations in both sections of the exams 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.

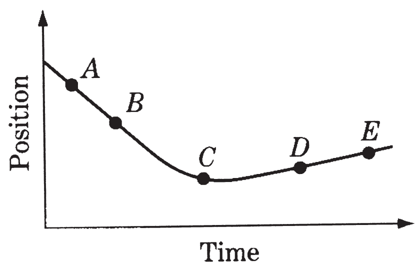
Physics B: Sample Multiple-Choice Questions

Most of the following sample questions, illustrative of the Physics B Exam, have appeared in past exams. The answers are on page 34. Additional questions can be found in the *2004 AP Physics B and Physics C Released Exams* book.

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 book). To simplify calculations, you may use $g = 10 \text{ m/s}^2$ in all problems.

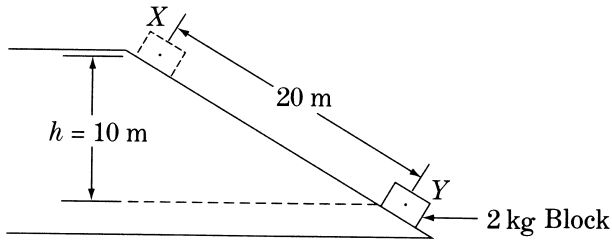
Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case.

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*

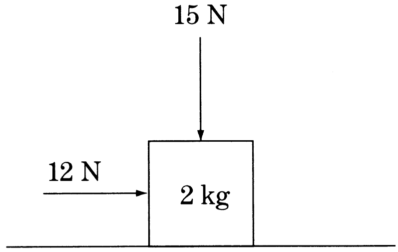
Questions 3-4



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.

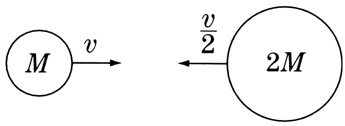
3. The magnitude of the net force on the block while it is sliding is most nearly
   (A) 0.1 N
   (B) 0.4 N
   (C) 2.5 N
   (D) 5.0 N
   (E) 10.0 N

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



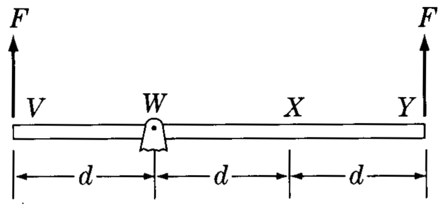
5. A block of mass 2 kg slides along a horizontal tabletop. A horizontal applied force of 12 N and a vertical applied force of 15 N act on the block, as shown above. If the coefficient of kinetic friction between the block and the table is 0.2, the frictional force exerted on the block is most nearly

(A) 1 N
(B) 3 N
(C) 4 N
(D) 5 N
(E) 7 N



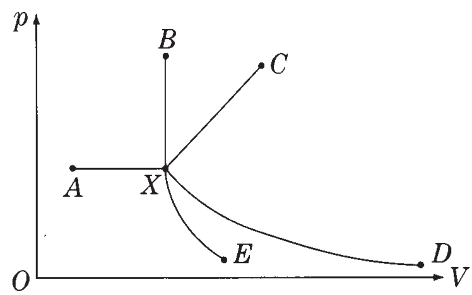
6. A ball of mass M and speed v collides head-on with a ball of mass $2M$ and speed $\frac{v}{2}$, as shown above. If the two balls stick together, their speed after the collision is

(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.

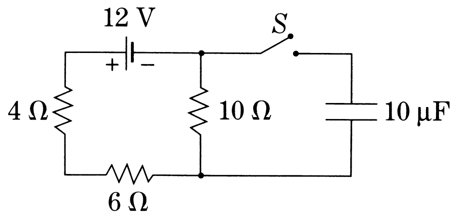


9. In the pV diagram above, the initial state of a gas is shown at point X. Which of the curves represents a process in which no work is done on or by the gas?
   (A) XA
   (B) XB
   (C) XC
   (D) XD
   (E) XE

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?

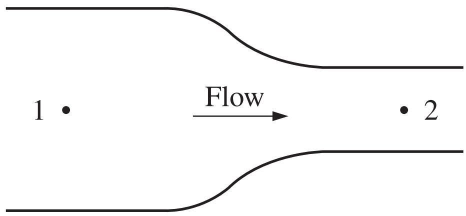
	Point *P*	Point *T*
(A)	Left	Right
(B)	Right	Left
(C)	Left	Toward the top of the page
(D)	Right	Toward the top of the page
(E)	Left	Toward the bottom of the page

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



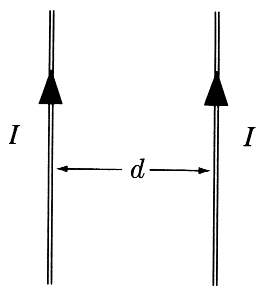
11. What is the current in the 4 Ω resistor while the switch S is open?
    (A) 0 A
    (B) 0.6 A
    (C) 1.2 A
    (D) 2.0 A
    (E) 3.0 A

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



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

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



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

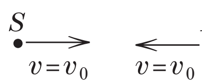
15. A source S of sound and a listener L each can be at rest or can move directly toward or away from each other with speed v_0. In which of the following situations will the observer hear the lowest frequency of sound from the source?

(A)


(B)


(C)


(D)

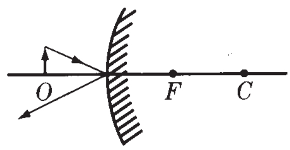

(E)


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

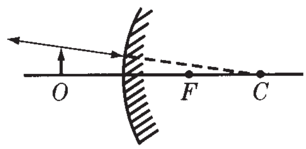
(A) 4×10^{-7} m/s
(B) 9×10^{-7} m/s
(C) 2×10^{8} m/s
(D) 3×10^{8} m/s
(E) 4×10^{8} m/s

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

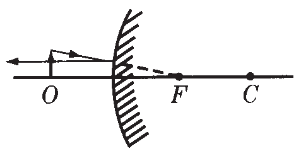
(A)



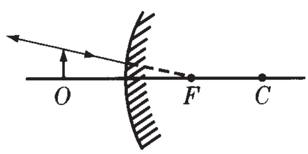
(B)



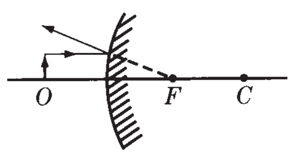
(C)



(D)



(E)



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

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

20. When ^{10}B is bombarded by neutrons, a neutron can be absorbed and an alpha particle (^{4}He) emitted. The kinetic energy of the reaction products is equal to the
    (A) kinetic energy of the incident neutron
    (B) total energy of the incident neutron
    (C) energy equivalent of the mass decrease in the reaction
    (D) energy equivalent of the mass decrease in the reaction, minus the kinetic energy of the incident neutron
    (E) energy equivalent of the mass decrease in the reaction, plus the kinetic energy of the incident neutron

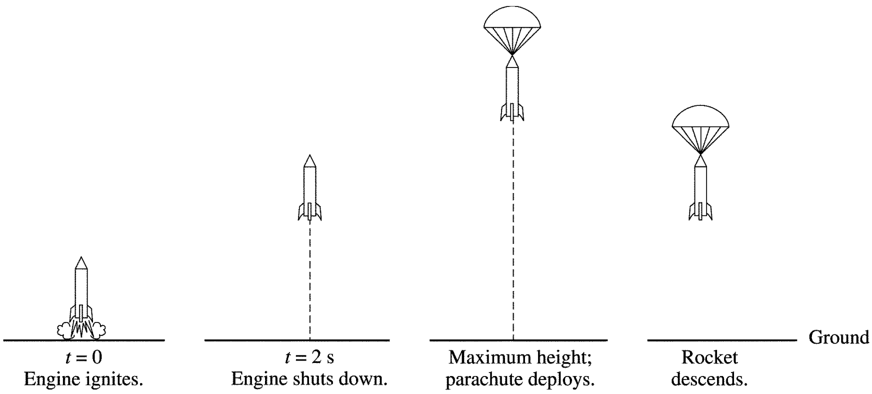
Answers to Physics B Multiple-Choice Questions

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

Physics B: Sample Free-Response Questions

The following seven questions constituted the complete free-response section of the 2002 AP Physics B Exam before the present exam format was instituted. All free-response questions released since 1999 can be found at AP Central.

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



Note: Figures not drawn to scale.

1. (15 points)

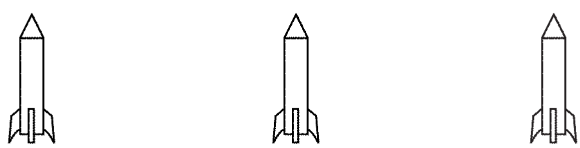
A model rocket of mass 0.250 kg is launched vertically with an engine that is ignited at time $t = 0$, as shown above. The engine provides an impulse of 20.0 N•s by firing for 2.0 s. Upon reaching its maximum height, the rocket deploys a parachute, and then descends vertically to the ground.

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

i. While the engine is firing

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

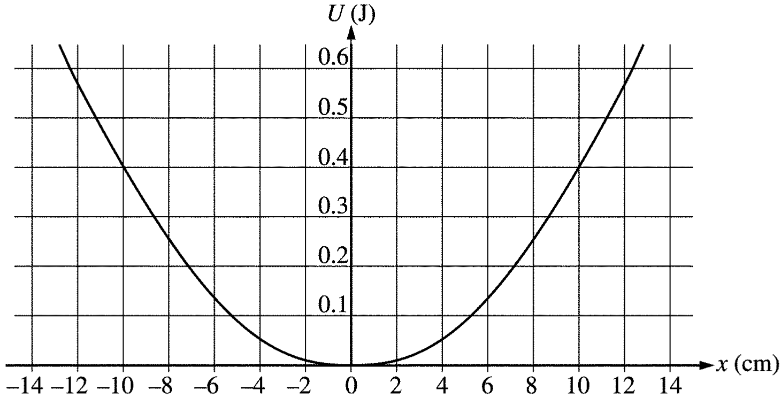
iii. After the parachute is deployed



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

(c) What maximum height will the rocket reach?

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



2. (15 points)

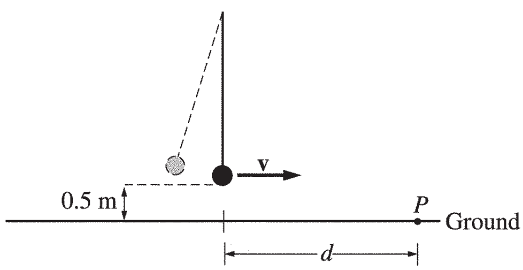
A 3.0 kg object subject to a restoring force F is undergoing simple harmonic motion with a small amplitude. The potential energy U of the object as a function of distance x from its equilibrium position is shown above. This particular object has a total energy E of 0.4 J.

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

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

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

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



Note: Figure not drawn to scale.

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

3. (15 points)

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

(a) The two bulbs are first connected in parallel to a 120 V source.
  i. Determine the resistance of the bulb rated 30 W and the current in it when it is connected in this circuit.
  ii. Determine the resistance of the bulb rated 40 W and the current in it when it is connected in this circuit.

(b) The bulbs are now connected in series with each other and a 120 V source.
  i. Determine the resistance of the bulb rated 30 W and the current in it when it is connected in this circuit.
  ii. Determine the resistance of the bulb rated 40 W and the current in it when it is connected in this circuit.

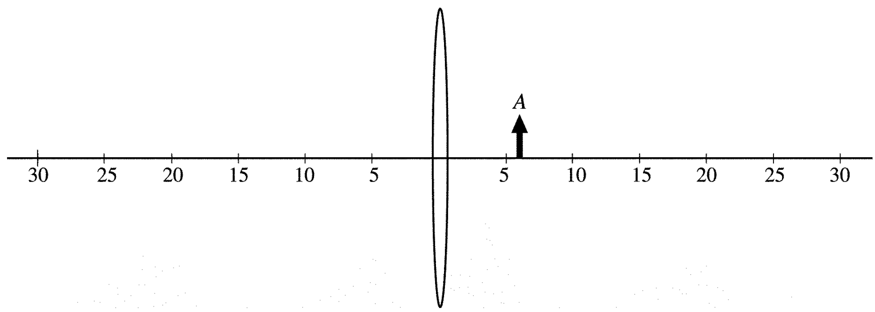
(c) In the spaces below, number the bulbs in each situation described, in order of their brightness.
(1 = brightest, 4 = dimmest)
  ____ 30 W bulb in the parallel circuit
  ____ 40 W bulb in the parallel circuit
  ____ 30 W bulb in the series circuit
  ____ 40 W bulb in the series circuit

(d) Calculate the total power dissipated by the two bulbs in each of the following cases.
  i. The parallel circuit
  ii. The series circuit

4. (15 points)

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

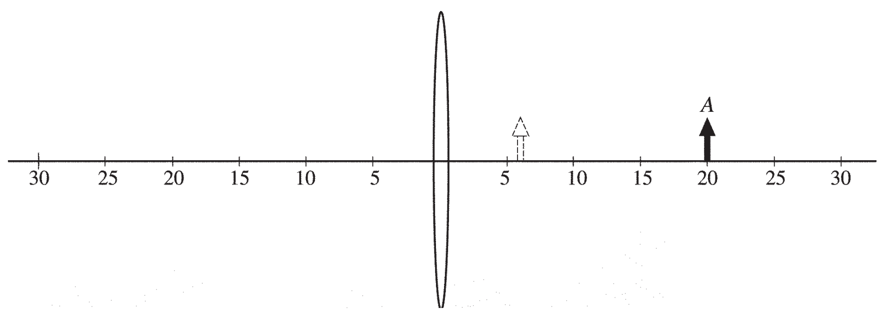
(a) On the figure below, draw a ray diagram showing the position and size of the image formed.



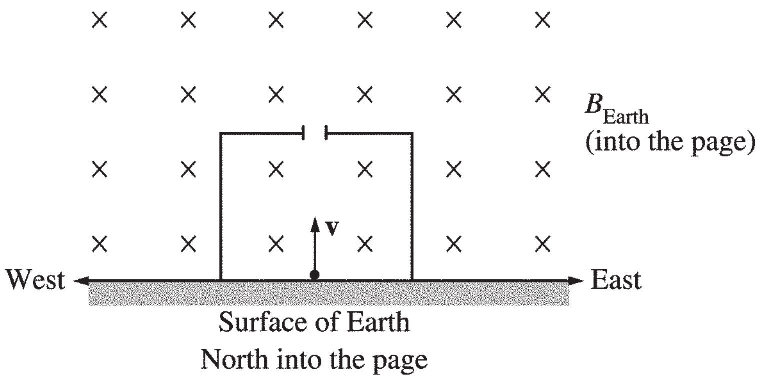
(b) State whether the image is real or virtual. Explain your reasoning.

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

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



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



5. (10 points)

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

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

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

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

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

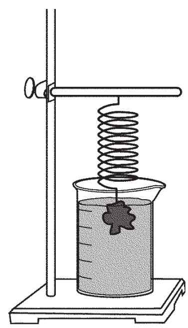
(d) Determine the magnitude of the acceleration a of the proton just after it leaves the box, in terms of the given quantities and fundamental constants.

6. (10 points)

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

- A metric ruler
- A stopwatch
- String

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



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

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

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

Symbol	Physical quantity

7. (10 points)

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

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

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

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

____ Increased ____ Decreased

Explain your reasoning.

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

Physics C Mechanics: Sample Multiple-Choice Questions

Most of the following sample questions have appeared in past exams. The answers are on page 47. Additional questions can be found in the *2004 AP Physics B and Physics C Released Exams* book.

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 book). 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

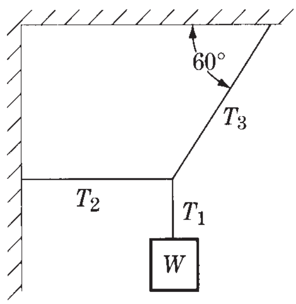
The speed v of an automobile moving on a straight road is given in meters per second as a function of time t in seconds by the following equation:

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

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

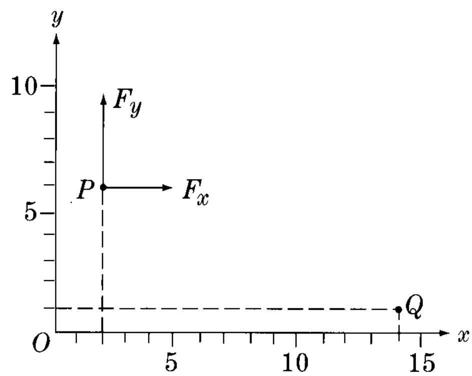
2. How far has the automobile traveled in the interval between $t = 0$ and $t = 2$ s?
   (A) 16 m
   (B) 20 m
   (C) 24 m
   (D) 32 m
   (E) 72 m

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



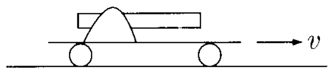
4. A system in equilibrium consists of an object of weight W that hangs from three ropes, as shown above. The tensions in the ropes are T_1, T_2, and T_3. Which of the following are correct values of T_2 and T_3?

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



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

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



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

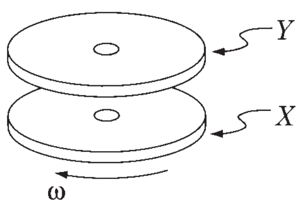
   (A) $\frac{Mv}{m}$

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

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

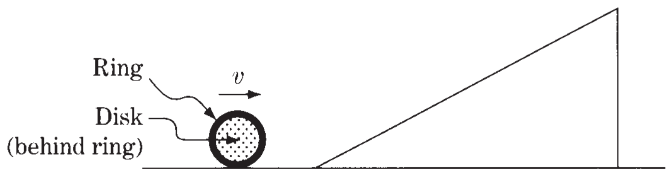
   (D) $\frac{mv}{M}$

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



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

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



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

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

Answers to Physics C Mechanics Multiple-Choice Questions

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

Physics C Mechanics: Sample Free-Response Questions

The following three questions constituted the complete free-response section for the Mechanics part of the 2002 AP Physics C Exam. All free-response questions released since 1999 can be found at AP Central.

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

Mech 1.

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

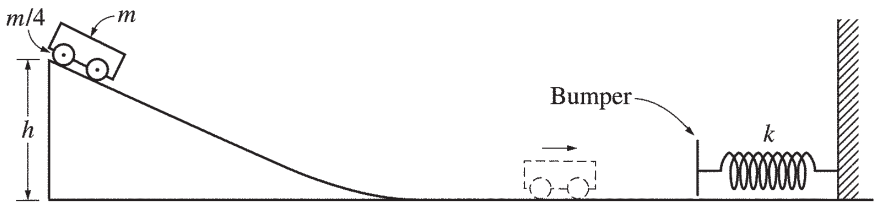
$$v = \frac{8}{1 + 5t}.$$

(a) Calculate the mass M of the object.

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

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

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



Mech 2.

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

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

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

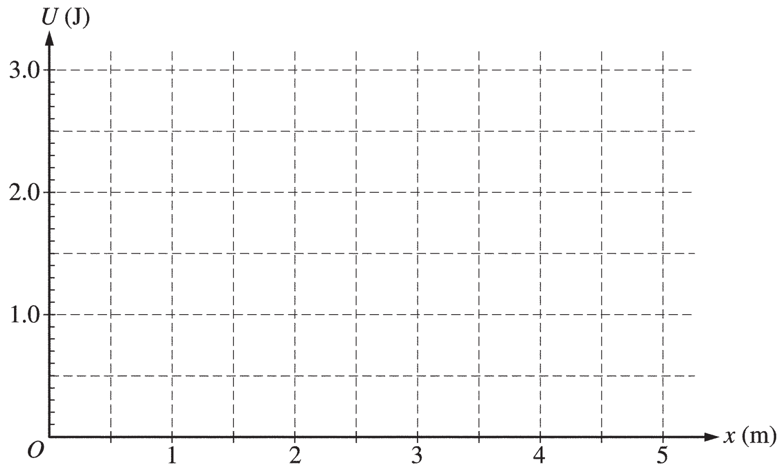
(c) After rolling down the incline and across the horizontal surface, the cart collides with a bumper of negligible mass attached to an ideal spring, which has a spring constant k. Determine the distance x_m the spring is compressed before the cart and bumper come to rest.

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

Mech 3.

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

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



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

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

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

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

____ Meterstick ____ Stopwatch ____ Photogate timer

____ String ____ Spring ____ Balance

____ Wood block ____ Set of objects of different masses

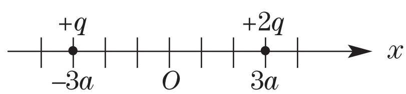
(e) Briefly outline the procedure you will use, being explicit about what measurements you need to make in order to determine the speed. You may include a labeled diagram of your setup if it will clarify your procedure.

Physics C Electricity and Magnetism: Sample Multiple-Choice Questions

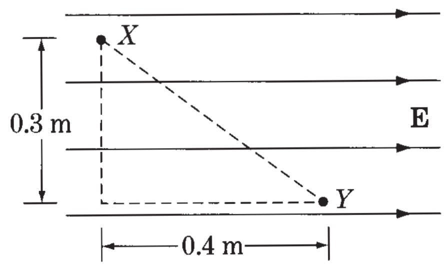
Most of the following sample questions have appeared in past exams. The answers are on page 58. Additional questions can be found in the *2004 AP Physics B and Physics C Released Exams* book.

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 book).

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.

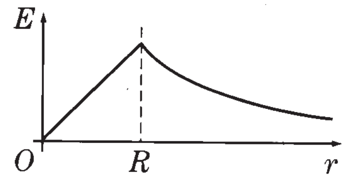


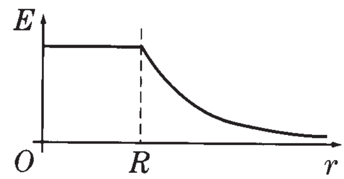
1. Two charges are located on the x-axis of a coordinate system as shown above. The charge $+2q$ is located at $x = +3a$ and the charge $+q$ is located at $x = -3a$. Where on the x-axis should an additional charge $+4q$ be located to produce an electric field equal to zero at the origin O?
   (A) $x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

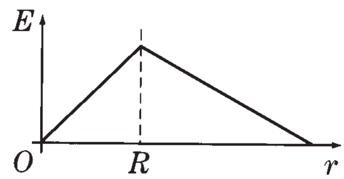


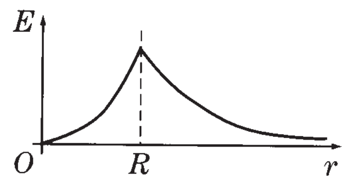
2. A uniform electric field **E** of magnitude 6,000 V/m exists in a region of space as shown above. What is the electric potential difference, $V_X - V_Y$, between points X and Y?
   (A) –12,000 V
   (B) 0 V
   (C) 1,800 V
   (D) 2,400 V
   (E) 3,000 V

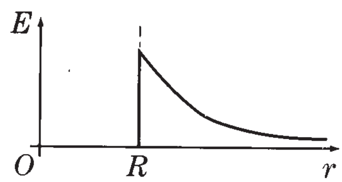
3. Charge is distributed uniformly throughout a long nonconducting cylinder of radius R. Which of the following graphs best represents the magnitude of the resulting electric field E as a function of r, the distance from the axis of the cylinder?

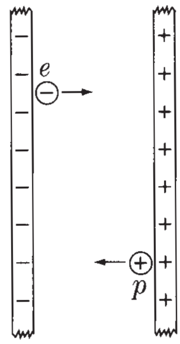
(A)


(B)


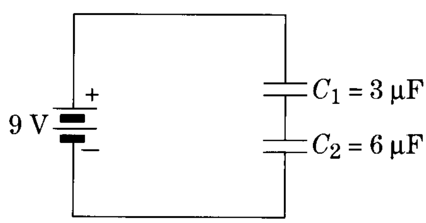
(C)


(D)


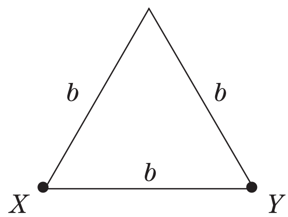
(E)




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

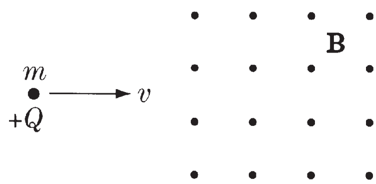
(B) $3\frac{A}{\rho b}$

(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.

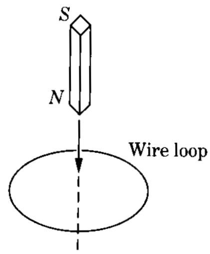
7. Which of the following best indicates the magnitude and the direction of the magnetic force **F** on the charge just after the charge enters the magnetic field?

	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

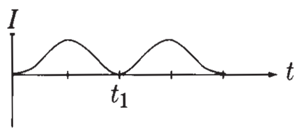
8. If the magnetic field strength is increased, which of the following will be true about the radius R?

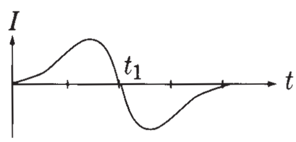
I. R increases if the incident speed is held constant.
II. For R to remain constant, the incident speed must be increased.
III. For R to remain constant, the incident speed must be decreased.

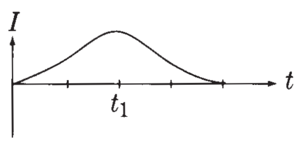
(A) I only
(B) II only
(C) III only
(D) I and II only
(E) I and III only

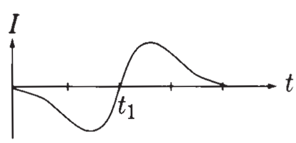


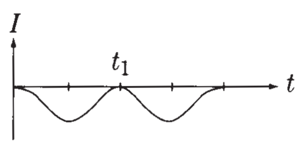
9. A bar magnet is lowered at constant speed through a loop of wire as shown in the diagram above. The time at which the midpoint of the bar magnet passes through the loop is t_1. Which of the following graphs best represents the time dependence of the induced current in the loop? (A positive current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

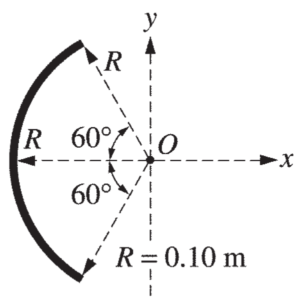
Answers to Physics C Electricity and Magnetism Multiple-Choice Questions

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 2002 AP Physics C Exam. All free-response questions released since 1999 can be found at AP Central.

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



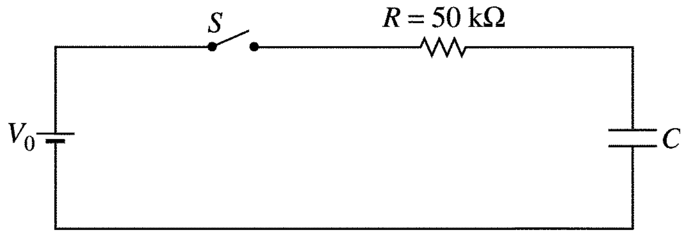
E&M 1.

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

(a) Determine the total charge on the rod.
(b) Determine the magnitude and direction of the electric field at the center O of the arc.
(c) Determine the electric potential at point O.

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

(d) Determine the magnitude and direction of the force that must be applied in order to keep the proton at rest.
(e) The proton is now released. Describe in words its motion for a long time after its release.



E&M 2.

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

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

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

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

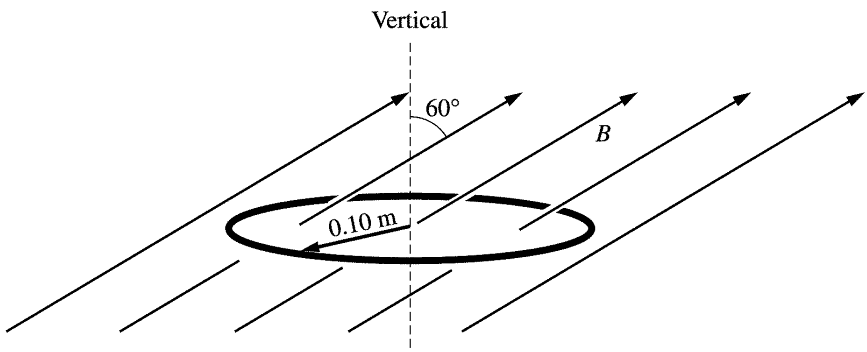
i. Give one possible explanation for this finding.

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

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

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

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

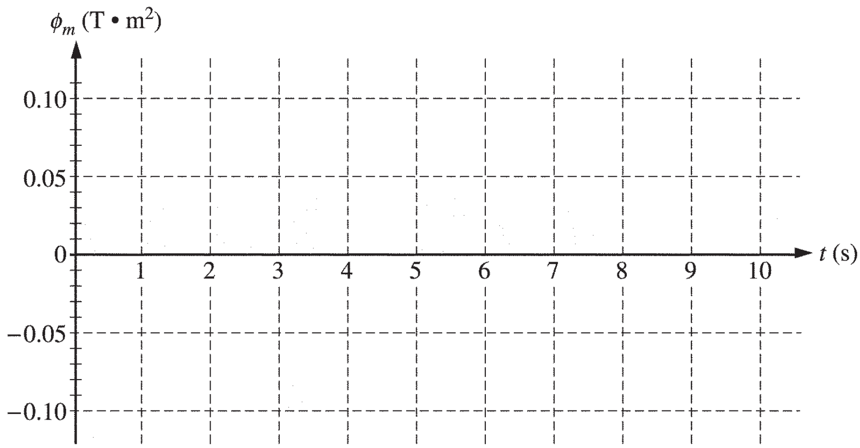


E&M 3.

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

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

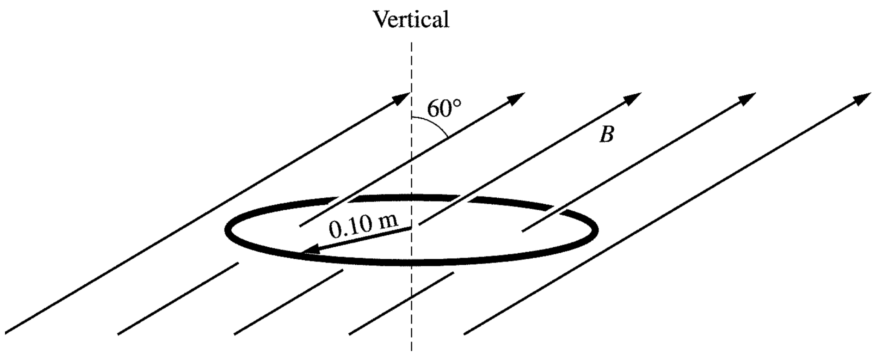
(b) Graph the magnetic flux ϕ_m as a function of time on the axes below.



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

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

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



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

AP® Program Essentials

The AP Reading

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

If you are an AP teacher or a college faculty member and would like to serve as a Reader, you can apply online at apcentral.collegeboard.com/reader. Alternatively, you can send an e-mail to apreader@ets.org, or call Performance Assessment Scoring Services at 609 406-5384.

AP Grades

The Readers' scores on the essay and problem-solving questions are combined with the results of the computer-scored multiple-choice questions, and the total raw scores are converted to a composite score on 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 national percentiles. Grade distribution charts are available at AP Central, as is information on how the grade boundaries for each AP grade are established. Grade distribution charts are also available on the AP student site at www.collegeboard.com/apstudents.

Why Colleges Grant Credit, Placement, or Both for AP Grades

Colleges know that the AP grades of 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 AP Program processes:

- College faculty serve on the committees that develop the Course Descriptions and exams in each AP course.
- 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 reviewed and updated regularly, based on the results of curriculum surveys at up to 200 colleges and universities, collaborations among the College Board and key educational and disciplinary organizations, and the interactions of committee members with professional organizations in their discipline.
- Periodic 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 to 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 students with 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 compared favorably, on the basis of their college grades, with students who completed the prerequisite first course in college, then took the second, higher level course in the subject area. Such studies answer the question of greatest concern to colleges: Are AP students who are exempted from introductory courses as well prepared to continue in a subject area as students who took their first course in college? To see the results of several college validity studies, go to AP Central. (The complete Morgan and Ramist study can be downloaded from the site.)

Guidelines on Setting Credit and Placement Policies for AP Grades

The College Board has created two useful resources for admissions administrators and academic faculty who need guidance on setting an AP policy for their college or university. The printed guide *AP and Higher Education* provides guidance for colleges and universities in setting AP credit and placement policies. The booklet details how to set an AP policy, summarizes AP research studies, and describes in detail course and exam development and the exam scoring process. AP Central has a section geared toward colleges and universities that provides similar information and additional resources, including links to all AP research studies, released exam questions, and sample student responses at varying levels of achievement for each AP Exam. Visit apcentral.collegeboard.com/highered.

The *Advanced Placement Policy Guide* for each AP subject field is designed for college faculty responsible for setting their department's AP policy. These folios provide content specific to each AP Exam, including validity research studies and a description of the AP course curriculum. Ordering information for these and other publications can be found in the AP Publications and Other Resources section of this Course Description.

College and University AP Credit and Placement Policies

Each college and university sets its own AP credit and placement policies. The AP Program has created a new online search tool, AP Credit Policy Info, that provides links to credit and placement policies at hundreds of colleges and universities. The tool helps students find the credit hours and advanced placement they can receive for qualifying exam scores within each AP subject. AP Credit Policy Info is available at www.collegeboard.com/ap/creditpolicy.

AP Scholar Awards

The AP Program offers a number of AP Scholar Awards to recognize high school students who have demonstrated college-level achievement through consistently high performance on AP Exams. Although there is no monetary award, students receive an award certificate, and the achievement is acknowledged on any grade report sent to colleges following the announcement of the awards. For detailed information about AP Scholar Awards (including qualification criteria), visit AP Central or contact the College Board's national office. Students can find this information at www.collegeboard.com/apstudents.

AP Calendar

The *AP Program Guide* for education professionals and the *Bulletin for AP Students and Parents* provide important Program information and details on the key events in the AP calendar. Information on ordering or downloading these publications can be found at the back of this book.

Exam Security

All parts of every AP Exam must be kept secure at all times. Forty-eight hours after the exam has been administered, the inserts containing the free-response questions (Section II) can be made available for teacher and student review.* **However, the multiple-choice section (Section I) must remain secure both before and after the exam administration.** No one other than students taking the exam can ever have access to or see the questions contained in Section I—this includes AP Coordinators and all teachers. The multiple-choice section must never be shared, copied in any manner, or reconstructed by teachers and students after the exam. **Schools that knowingly or unknowingly violate these policies will not be permitted to administer AP Exams in the future and may be held responsible for any damages or losses the College Board and/or ETS incur in the event of a security breach.**

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

To ensure that all students have an equal opportunity to demonstrate their abilities on the exam, AP Exams must be administered in a uniform manner. **It is extremely important to follow the administration schedule and all procedures outlined in detail in the most recent *AP Coordinator's Manual*.** Please note that AP Studio Art portfolios and their contents are not considered secure testing materials; see the *AP Coordinator's Manual* and the appropriate *AP Examination Instructions* book for further information. The manual also includes directions on how to handle misconduct and other security problems. All schools participating in AP automatically receive printed copies of the *Manual*. It is also available in PDF format at apcentral.collegeboard.com/coordinators.

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

Any breach of security should be reported to the Office of Testing Integrity immediately (call 800 353-8570 or 609 406-5427, fax 609 406-9709, or e-mail tsreturns@ets.org).

Teacher Support

AP Central® (apcentral.collegeboard.com)

You can find the following Web resources at AP Central (free registration required):

- AP Course Descriptions, AP Exam questions and scoring guidelines, sample syllabi, research reports, and feature articles.
- A searchable Institutes and Workshops database, providing information about professional development events. AP Central offers online events that participants can access from their home or school computers.
- The Course Home Pages (apcentral.collegeboard.com/coursehomepages), which contain insightful articles, teaching tips, activities, lab ideas, and other course-specific content contributed by colleagues in the AP community.
- In-depth FAQs, including brief responses to frequently asked questions about AP courses and exams, the AP Program, and other topics of interest.
- Links to AP publications and products (some available for immediate download) that can be purchased online at the College Board Store (store.collegeboard.com).
- Moderated electronic discussion groups (EDGs) for each AP course to facilitate the exchange of ideas and practices.
- Teachers' Resources database—click on the "Teachers' Resources" tab to search for reviews of textbooks, reference books, documents, Web sites, software, videos, and more. College and high school faculty write the reviews with specific reference to the value of the resources in teaching AP courses.

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

Online Workshops and Events

College Board online events and workshops are designed to help support and expand the high level of professional development currently offered teachers in workshops and AP Summer Institutes. Because of budgetary, geographical, and time constraints, not all teachers and administrators are able to take advantage of live, face-to-face workshops. The College Board develops and offers both standard and customized online events and workshops for schools, districts, and states, which are available in both live and archival formats. Online events and workshops are developed and presented by experienced College Board consultants and guest speakers; online workshops are equivalent to one-day, face-to-face workshops.

Pre-AP®

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

Pre-AP is based on the following premises. The first is the expectation that all students can perform at rigorous academic levels. This expectation should be reflected in the curriculum and instruction throughout the school so that all students are consistently being challenged to bring their knowledge and skills to the next level.

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

Pre-AP teacher professional development explicitly supports the goal of college as an option for every student. It is important to have a recognized standard for college-level academic work. The AP Program provides these standards for Pre-AP. Pre-AP professional development resources reflect the topics, concepts, and skills taught in AP courses and assessed in AP Exams.

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

Pre-AP Professional Development

Pre-AP professional development is available through workshops and conferences coordinated by the College Board's regional offices. Pre-AP professional development is divided into three categories:

1. **Vertical Teaming**—Articulation of content and pedagogy across the middle school and high school years. The emphasis is on aligning curricula and improving teacher communication. The intended outcome is a coordinated program of teaching skills and concepts over several years.

2. **Classroom Strategies**—Content-specific classroom strategies for middle school and high school teachers. Various approaches, techniques, and ideas are emphasized.

3. **Instructional Leadership**—Administrators and other instructional leaders examine how to use Pre-AP professional development—especially AP Vertical Teams®—to create a system that challenges all students to perform at rigorous academic levels.

For a complete list of Pre-AP professional development offerings, please contact your regional office or visit AP Central.

AP Publications and Other Resources

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

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

Free Resources

Copies of the following items can be ordered free of charge at apcentral.collegeboard.com/freepubs. Items marked with a computer mouse icon 🖱 can be downloaded for free from AP Central.

The Value of AP Courses and Exams — A, SP, T

This brochure can be used by school counselors and administrators to provide parents and students with information about the many benefits of participation in AP courses and exams.

AP Tools for Schools Resource Kit — A

This complimentary resource assists schools in building their AP programs. The kit includes the new video *Experience College Success*, the brochure *The Value of AP Courses and Exams*, and brief descriptions of the AP Credit Policy Info search and the Parent's Night PowerPoint presentation.

Experience College Success is a six-minute video that provides a short overview of the AP Program, with commentary from admissions officers, college students, and high school faculty about the benefits of participation in AP courses. Each videotape includes both an English and Spanish version.

Bulletin for AP Students and Parents — SP

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

Opening Classroom Doors: Strategies for Expanding Access to AP — A, T

Increasing AP participation while maintaining the Program's high academic standards is a challenge for many schools. This booklet profiles best practices from urban, suburban, and rural schools nationwide that have successfully met this challenge, and offers powerful strategies for fostering a culture of excellence and equity.

Get with the Program — SP

All students, especially those from underserved backgrounds, should understand the value of a high-quality education. Written especially for students and their families, this bilingual (Spanish/English) brochure highlights the benefits of participation in the AP Program. (The brochure can be ordered in large quantities for students in grades 8–12.)

AP Program Guide **A**

This guide takes the AP Coordinator through the school year step-by-step—organizing an AP program, ordering and administering the AP Exams, AP Exam payment, and grade reporting. It also includes information on teacher professional development, AP resources, and exam schedules.

AP and Higher Education **A, C, T**

This publication is intended to inform and help education professionals at the secondary and postsecondary levels understand the benefits of having a coherent, equitable AP credit and placement policy. Topics included are the development of AP courses and exams, grading of AP Exams, exam validation, research studies comparing the performance of AP students with non-AP students, uses of AP Exams by students in college, and how faculty can get involved in the AP Program.

Advanced Placement Policy Guides **A, C, T**

These policy guides are designed for college faculty responsible for setting their department's AP policy, and provide, in a subject-specific context, information about AP validity studies, college faculty involvement, and AP course curricular content. There are separate guides for each AP subject field.

Priced Publications

The following items can be ordered through the College Board Store at store.collegeboard.com. Alternatively, you can download an AP Order Form from AP Central at apcentral.collegeboard.com/documentlibrary.

Course Descriptions **A, C, SP, T**

Course Descriptions are available for each AP subject. They provide an outline of each AP course's content, explain the kinds of skills students are expected to demonstrate in the corresponding introductory college-level course, and describe the AP Exam. Sample multiple-choice questions with an answer key and sample free-response questions are included.

Note: PDF versions of current AP Course Descriptions for each AP subject may be downloaded free of charge from AP Central and the College Board's Web site for students. Follow the above instructions to purchase printed copies. (The Course Description for AP Computer Science is available in electronic format only.)

Released Exams **C, T**

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

Teacher's Guides **T**

For those about to teach an AP course for the first time, or for experienced AP teachers who would like to get some fresh ideas for the classroom, the *Teacher's Guide* is an excellent resource. Each *Teacher's Guide* contains syllabi developed by high school teachers currently teaching the AP course and college faculty who teach the equivalent course at colleges and universities. Along with detailed course outlines and innovative teaching tips, you'll also find extensive lists of suggested teaching resources.

AP Vertical Teams® Guides **A, T**

AP Vertical Teams (APVT) are made up of teachers from different grade levels who work together to develop and implement a sequential curriculum in a given discipline. Teams help students acquire the skills necessary for success in AP courses. To assist teachers and administrators who are interested in establishing an APVT at their school, the College Board has published these guides: *AP Vertical Teams Guide for English; Advanced Placement Mathematics Vertical Teams Toolkit; AP Vertical Teams Guide for Science; AP Vertical Teams Guide for Social Studies; AP Vertical Teams Guide for Fine Arts*, *Vol. 1: Studio Art; AP Vertical Teams Guide for Fine Arts*, *Vol. 2: Music Theory;* and *AP Vertical Teams Guide for Fine Arts*, *Vols. 1 and 2* (set).

Multimedia APCD® (home version, multinetwork site license) **SP, T**

These CD-ROMs are available for AP Calculus AB, AP English Language, AP English Literature, AP European History, and AP 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. Also included are a listing of resources for further study and a planner to help students schedule and organize their study time.

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

Electronic Publications

Additional supplemental publications are available in electronic format to be purchased and downloaded from the College Board Store. These include a collection of 13 World History Teaching Units, calculus free-response questions and solutions from 1969 to 1997, the *Physics Lab Guide*, and a collection of Java syllabi for Computer Science.

Announcements of new electronic publications can be found on the AP Course Home Pages on AP Central (apcentral.collegeboard.com/coursehomepages).

Table of Information and Equation Tables for AP Physics Exams

The accompanying Table of Information and Equation Tables will be provided to students when they take the AP Physics Exams. Therefore, students may NOT bring their own copies of these tables to the examination room, although they may use them throughout the year in their classes in order to become familiar with their content.

Table of Information

For both the Physics B and Physics C Exams, the Table of Information is printed near the front cover of the multiple-choice section and on the green insert provided with the free-response section. The tables are identical for both exams except for one convention as noted.

Equation Tables

For both the Physics B and Physics C Exams, the equation tables for each exam are printed only on the green insert provided with the free-response section. The equation tables may be used by students when taking the free-response sections of both exams, but NOT when taking the multiple-choice sections.

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

The equation tables are grouped in sections according to the major content category in which they appear. Within each section, the symbols used for the variables in that section 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.

Some explanations about notation used in the equation tables:

1. The symbols used for physical constants are the same as those in the Table of Information and are defined in the Table of Information rather than in the right-hand columns of the tables.
2. Symbols in bold face represent vector quantities.
3. Subscripts on symbols in the equations are used to represent special cases of the variables defined in the right-hand columns.
4. The symbol Δ before a variable in an equation specifically indicates a change in the variable (i.e., final value minus initial value).
5. Several different symbols (e.g. d, r, s, h, ℓ) are used for linear dimensions such as length. The particular symbol used in an equation is one that is commonly used for that equation in textbooks.

TABLE OF INFORMATION FOR 2006 and 2007

CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\ \text{u} = 1.66 \times 10^{-27}\ \text{kg}$
	$= 931\ \text{MeV}/c^2$
Proton mass,	$m_p = 1.67 \times 10^{-27}\ \text{kg}$
Neutron mass,	$m_n = 1.67 \times 10^{-27}\ \text{kg}$
Electron mass,	$m_e = 9.11 \times 10^{-31}\ \text{kg}$
Electron charge magnitude,	$e = 1.60 \times 10^{-19}\ \text{C}$
Avogadro's number,	$N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$
Universal gas constant,	$R = 8.31\ \text{J/(mol•K)}$
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}\ \text{J/K}$
Speed of light,	$c = 3.00 \times 10^{8}\ \text{m/s}$
Planck's constant,	$h = 6.63 \times 10^{-34}\ \text{J•s}$
	$= 4.14 \times 10^{-15}\ \text{eV•s}$
	$hc = 1.99 \times 10^{-25}\ \text{J•m}$
	$= 1.24 \times 10^{3}\ \text{eV•nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N•m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}\ \text{N•m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}\ \text{(T•m)/A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}\ \text{(T•m)/A}$
Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg•s}^2$
Acceleration due to gravity at Earth's surface,	$g = 9.8\ \text{m/s}^2$
1 atmosphere pressure,	$1\ \text{atm} = 1.0 \times 10^{5}\ \text{N/m}^2$
	$= 1.0 \times 10^{5}\ \text{Pa}$
1 electron volt,	$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$

UNITS

Name	Symbol
meter	m
kilogram	kg
second	s
ampere	A
kelvin	K
mole	mol
hertz	Hz
newton	N
pascal	Pa
joule	J
watt	W
coulomb	C
volt	V
ohm	Ω
henry	H
farad	F
tesla	T
degree Celsius	°C
electron-volt	eV

PREFIXES

Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	sin θ	cos θ	tan θ
0°	0	1	0
30°	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
37°	3/5	4/5	3/4
45°	$\sqrt{2}/2$	$\sqrt{2}/2$	1
53°	4/5	3/5	4/3
60°	$\sqrt{3}/2$	1/2	$\sqrt{3}$
90°	1	0	∞

The following conventions are used in this exam.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.
II. The direction of any electric current is the direction of flow of positive charge (conventional current).
III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.
*IV. For mechanics and thermodynamics equations, *W* represents the work done on a system.

*Not on the Table of Information for Physics C, since Thermodynamics is not a Physics C topic.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2006 and 2007

NEWTONIAN MECHANICS

$$v = v_0 + at$$

$$x = x_0 + v_0 t + \frac{1}{2}at^2$$

$$v^2 = v_0^2 + 2a(x - x_0)$$

$$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$$

$$F_{fric} \le \mu N$$

$$a_c = \frac{v^2}{r}$$

$$\tau = rF \sin\theta$$

$$\mathbf{p} = m\mathbf{v}$$

$$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$$

$$K = \frac{1}{2}mv^2$$

$$\Delta U_g = mgh$$

$$W = F\Delta r \cos\theta$$

$$P_{avg} = \frac{W}{\Delta t}$$

$$P = Fv\cos\theta$$

$$\mathbf{F}_s = -k\mathbf{x}$$

$$U_s = \frac{1}{2}kx^2$$

$$T_s = 2\pi\sqrt{\frac{m}{k}}$$

$$T_p = 2\pi\sqrt{\frac{\ell}{g}}$$

$$T = \frac{1}{f}$$

$$F_G = -\frac{Gm_1m_2}{r^2}$$

$$U_G = -\frac{Gm_1m_2}{r}$$

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
T = period
t = time
U = potential energy
v = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$$F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}$$

$$\mathbf{E} = \frac{\mathbf{F}}{q}$$

$$U_E = qV = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r}$$

$$E_{avg} = -\frac{V}{d}$$

$$V = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$$

$$C = \frac{Q}{V}$$

$$C = \frac{\epsilon_0 A}{d}$$

$$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$$

$$I_{avg} = \frac{\Delta Q}{\Delta t}$$

$$R = \frac{\rho\ell}{A}$$

$$V = IR$$

$$P = IV$$

$$C_p = \sum_i C_i$$

$$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$$

$$R_s = \sum_i R_i$$

$$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$$

$$F_B = qvB\sin\theta$$

$$F_B = BI\ell\sin\theta$$

$$B = \frac{\mu_0}{2\pi}\frac{I}{r}$$

$$\phi_m = BA\cos\theta$$

$$\mathcal{E}_{avg} = -\frac{\Delta\phi_m}{\Delta t}$$

$$\mathcal{E} = B\ell v$$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
v = velocity or speed
ρ = resistivity
θ = angle
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 2006 and 2007

FLUID MECHANICS AND THERMAL PHYSICS

$$P = P_0 + \rho g h$$

$$F_{buoy} = \rho V g$$

$$A_1 \upsilon_1 = A_2 \upsilon_2$$

$$P + \rho g y + \frac{1}{2}\rho \upsilon^2 = \text{const.}$$

$$\Delta \ell = \alpha \ell_0 \Delta T$$

$$H = \frac{kA\Delta T}{L}$$

$$P = \frac{F}{A}$$

$$PV = nRT = Nk_B T$$

$$K_{avg} = \frac{3}{2}k_B T$$

$$\upsilon_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$$

$$W = -P\Delta V$$

$$\Delta U = Q + W$$

$$e = \left|\frac{W}{Q_H}\right|$$

$$e_c = \frac{T_H - T_C}{T_H}$$

A = area
e = efficiency
F = force
h = depth
H = rate of heat transfer
k = thermal conductivity
K_{avg} = average molecular kinetic energy
ℓ = length
L = thickness
M = molar mass
n = number of moles
N = number of molecules
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
υ = velocity or speed
υ_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$$E = hf = pc$$

$$K_{\max} = hf - \phi$$

$$\lambda = \frac{h}{p}$$

$$\Delta E = (\Delta m)c^2$$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$$\upsilon = f\lambda$$

$$n = \frac{c}{\upsilon}$$

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\sin\theta_c = \frac{n_2}{n_1}$$

$$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$$

$$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$$

$$f = \frac{R}{2}$$

$$d\sin\theta = m\lambda$$

$$x_m \sim \frac{m\lambda L}{d}$$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
υ = speed
x = position
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

Triangle
$A = \frac{1}{2}bh$

Circle
$A = \pi r^2$
$C = 2\pi r$

Parallelepiped
$V = \ell wh$

Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$

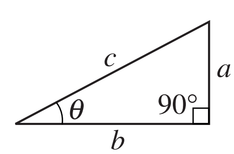
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

Right Triangle
$a^2 + b^2 = c^2$

$\sin\theta = \frac{a}{c}$

$\cos\theta = \frac{b}{c}$

$\tan\theta = \frac{a}{b}$



A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

ADVANCED PLACEMENT PHYSICS C EQUATIONS FOR 2006 and 2007

MECHANICS

$\upsilon = \upsilon_0 + at$

$x = x_0 + \upsilon_0 t + \frac{1}{2}at^2$

$\upsilon^2 = \upsilon_0^2 + 2a(x - x_0)$

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$

$\mathbf{F} = \frac{d\mathbf{p}}{dt}$

$\mathbf{J} = \int \mathbf{F}\, dt = \Delta \mathbf{p}$

$\mathbf{p} = m\mathbf{v}$

$F_{fric} \leq \mu N$

$W = \int \mathbf{F} \cdot d\mathbf{r}$

$K = \frac{1}{2}m\upsilon^2$

$P = \frac{dW}{dt}$

$P = \mathbf{F} \cdot \mathbf{v}$

$\Delta U_g = mgh$

$a_c = \frac{\upsilon^2}{r} = \omega^2 r$

$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$

$\sum \boldsymbol{\tau} = \boldsymbol{\tau}_{net} = I\boldsymbol{\alpha}$

$I = \int r^2 dm = \sum mr^2$

$\mathbf{r}_{cm} = \sum m\mathbf{r} / \sum m$

$\upsilon = r\omega$

$\mathbf{L} = \mathbf{r} \times \mathbf{p} = I\boldsymbol{\omega}$

$K = \frac{1}{2}I\omega^2$

$\omega = \omega_0 + \alpha t$

$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$

a = acceleration
F = force
f = frequency
h = height
I = rotational inertia
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
L = angular momentum
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
$\mathbf{r}$ = position vector
T = period
t = time
U = potential energy
υ = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque
ω = angular speed
α = angular acceleration

$\mathbf{F}_s = -k\mathbf{x}$

$U_s = \frac{1}{2}kx^2$

$T = \frac{2\pi}{\omega} = \frac{1}{f}$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$\mathbf{F}_G = -\frac{Gm_1m_2}{r^2}\hat{\mathbf{r}}$

$U_G = -\frac{Gm_1m_2}{r}$

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}$

$\mathbf{E} = \frac{\mathbf{F}}{q}$

$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{Q}{\epsilon_0}$

$E = -\frac{dV}{dr}$

$V = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$

$U_E = qV = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r}$

$C = \frac{Q}{V}$

$C = \frac{\kappa\epsilon_0 A}{d}$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$I = \frac{dQ}{dt}$

$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$

$R = \frac{\rho\ell}{A}$

$\mathbf{E} = \rho\mathbf{J}$

$I = Nev_dA$

$V = IR$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$P = IV$

$\mathbf{F}_M = q\mathbf{v} \times \mathbf{B}$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
J = current density
L = inductance
ℓ = length
n = number of loops of wire per unit length
N = number of charge carriers per unit volume
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential or stored energy
V = electric potential
υ = velocity or speed
ρ = resistivity
ϕ_m = magnetic flux
κ = dielectric constant

$\oint \mathbf{B} \cdot d\boldsymbol{\ell} = \mu_0 I$

$d\mathbf{B} = \frac{\mu_0}{4\pi}\frac{I\, d\boldsymbol{\ell} \times \mathbf{r}}{r^3}$

$\mathbf{F} = \int I\, d\boldsymbol{\ell} \times \mathbf{B}$

$B_s = \mu_0 nI$

$\phi_m = \int \mathbf{B} \cdot d\mathbf{A}$

$\mathcal{E} = -\frac{d\phi_m}{dt}$

$\mathcal{E} = -L\frac{dI}{dt}$

$U_L = \frac{1}{2}LI^2$

ADVANCED PLACEMENT PHYSICS C EQUATIONS FOR 2006 and 2007

GEOMETRY AND TRIGONOMETRY

Rectangle

$A = bh$

Triangle

$A = \frac{1}{2}bh$

Circle

$A = \pi r^2$

$C = 2\pi r$

Parallelepiped

$V = \ell wh$

Cylinder

$V = \pi r^2 \ell$

$S = 2\pi r\ell + 2\pi r^2$

Sphere

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

$S = 4\pi r^2$

Right Triangle

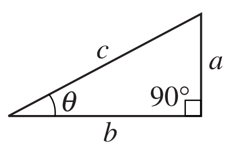
$a^2 + b^2 = c^2$

$\sin\theta = \frac{a}{c}$

$\cos\theta = \frac{b}{c}$

$\tan\theta = \frac{a}{b}$

A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius



CALCULUS

$$\frac{df}{dx} = \frac{df}{du}\frac{du}{dx}$$

$$\frac{d}{dx}\left(x^n\right) = nx^{n-1}$$

$$\frac{d}{dx}\left(e^x\right) = e^x$$

$$\frac{d}{dx}(\ln x) = \frac{1}{x}$$

$$\frac{d}{dx}(\sin x) = \cos x$$

$$\frac{d}{dx}(\cos x) = -\sin x$$

$$\int x^n\,dx = \frac{1}{n+1}x^{n+1},\ n \neq -1$$

$$\int e^x\,dx = e^x$$

$$\int \frac{dx}{x} = \ln|x|$$

$$\int \cos x\,dx = \sin x$$

$$\int \sin x\,dx = -\cos x$$

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