THE EXAMS

Each Physics C Exam is 1 hour and 30 minutes long. A student may take either or both exams, and separate scores are reported for each. The time for each exam 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 score. 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 use a setting involving principles from electricity and magnetism, 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. 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;
- 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; or
- derive relationships from fundamental 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, manipulating data to fit a certain model, especially a linear one;
- 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. Near the front of both the multiple-choice and free-response exam booklets, a Table of Information and tables of commonly used equations is provided. The Table of Information 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 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 page 59. Recent free-response sections can also be found on 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 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 C Exams the words "justify," "explain," "calculate," "what is," "determine," "derive," "sketch," and "plot" 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 C 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, or Gauss's law. 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 C 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 C Exam equation sheet. The final answer, usually algebraic, is then obtained through the appropriate use of mathematics.

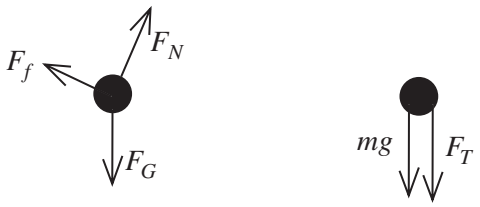
The words "sketch" and "plot" relate to student-produced graphs. "Sketch" means to draw a graph that illustrates key trends in a particular relationship, such as slope, curvature, intercept(s), or asymptote(s). Numerical scaling or specific data points are not required in a sketch. "Plot" means to draw the data points given in the problem on the grid provided, either using the given scale or indicating the scale and units when none are provided.

An exam question that requires the drawing of a free-body or force diagram will direct the students as follows:

> "On the dot below, which represents the [object], draw and label the forces (not components) that act on the [object]. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot",

where [object] is replaced by a reference specific to the question, such as "the car when it reaches the top of the hill." Any components that are included in the diagram

will be scored in the same way as incorrect or extraneous forces. Examples of acceptable free-body diagrams are shown below.



In addition, in any subsequent part asking for a solution that would typically make use of the diagram, the following will be included: "If you need to draw anything other than what you have shown in part [x] to assist in your solution, use the space below. Do NOT add anything to the figure in part [x]." This will give students the opportunity to construct a working diagram showing any components that are appropriate to the solution of the problem. This second diagram will not be scored.

The use of significant figures is an important skill in any introductory college physics course. However, this skill is rarely assessed on numerical problems on the actual AP exam. A general rule for the Physics C tests is to use 2 to 4 significant figures for all numerical answers.

There are exceptions to this general rule. When an AP problem is clearly a laboratory-based question and students are asked to manipulate data or sets of data, then the use of significant figures may be assessed in the actual scoring rubric. Another exception that could appear in the scoring of an AP problem is when students are asked to give numerical answers for known physical constants, and these answers clearly conflict with known information about that physical constant — such as stating that the mass of the electron is $9.1000000 \times 10^{-31}$ kg or that the acceleration due to gravity is $g = 9.9000000 \text{ m/s}^2$. Students have access to these known quantities (and associated significant figures) in the table of information provided with the exam.

Simplification of algebraic and numerical answers is encouraged, though it should always be balanced with students' efficient use of exam time. Simplifying an answer will often reveal a characteristic of the underlying physics that may be useful in a subsequent part of the exam question. A simplified answer is the clearest way to communicate with the professors and AP teachers who score the exams. Equivalent answers are entitled to full credit, and the Exam Readers always evaluate unsimplified answers for correctness. Yet, however careful the Readers are, there is always the chance for error in their evaluations, and thus simplification may be in the students' best interest.

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

Calculators and Equation Tables

Students will be allowed to use a calculator on the entire AP Physics C: Mechanics and Physics C: Electricity and Magnetism exams — including both the multiple-choice and free-response sections. Scientific or graphing calculators (including the approved graphing calculators listed at www.collegeboard.org/ap/calculators) may be used,

provided that they do not have any unapproved features or capabilities. Calculator memories do not need to be cleared before or after the exam. Since graphing calculators can be used to store data, including text, proctors should monitor that students are using their calculators appropriately. Communication between calculators is prohibited during the exam administration. Attempts by students to use the calculator to remove exam questions and/or answers from the room may result in the invalidation of AP Exam scores. The policy regarding the use of calculators on the AP Physics C exams was developed to address the rapid expansion of the capabilities of calculators, which include not only programming and graphing functions but also the availability of stored equations and other data. Students should be allowed to use the calculators to which they are accustomed. However, students should be encouraged to develop their skills in estimating answers and orders of magnitude quickly and in recognizing answers that are physically unreasonable or unlikely.

Tables containing equations commonly used in physics will be provided for students to use during the entire AP Physics C: Mechanics and Physics C: Electricity and Magnetism exams. In general, the equations for each year's exam are printed and distributed with the course and exam description at least a year in advance so that students can become accustomed to using them throughout the year. However, because the equation tables will be provided with the exam, students will NOT be allowed to bring their own copies to the exam room. The latest version of the equations and formulas list is included in Appendix B to this course and exam description. One of the purposes of providing the tables of commonly employed equations for use with the exam is to address the issue of equity for those students who do not have access to equations stored in their calculators. The availability of these equations to all students means that in the scoring of the exam, little or no credit will be awarded for simply writing down equations or for answers unsupported by explanations or logical development.

In general, the purpose of allowing calculators and equation sheets to be used in both sections of the exam is to place greater emphasis on the understanding and application of fundamental physical principles and concepts. For solving problems and writing essays, a sophisticated scientific or graphing calculator, or the availability of stored equations, is no substitute for a thorough grasp of the physics involved.