RELEASED EXAMS

1998 AP Physics B and Physics C

Contains:

- Multiple-Choice Questions and Answer Key
- Free-Response Questions, Scoring Guidelines, and Sample Student Responses and Commentary
- Statistical Information About Student Performance on the 1998 Exams

CollegeBoard AP

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The Advanced Placement Examinations in Physics—Physics B and Physics C

Contains:

- Information on the AP Process (pages 1-5)
- The 1998 AP Physics B Examination (pages 7-58)
- Answers to the 1998 AP Physics B Questions (pages 59-115). Includes:
  - Answer Key for the Multiple-Choice Section
  - Scoring Guidelines for the Free-Response Questions
  - Sample Student Responses and Commentary
- The 1998 AP Physics C Examination (pages 117-165)
- Answers to the 1998 AP Physics C Questions (pages 167-215). Includes:
  - Answer Key for the Multiple-Choice Section
  - Scoring Guidelines, Sample Student Responses, and Commentary for Physics C: Mechanics
  - Scoring Guidelines, Sample Student Responses, and Commentary for Physics C: Electricity & Magnetism
- Statistical Information About Student Performance on the 1998 AP Physics Exams (pages 217-227).

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THE COLLEGE BOARD: EDUCATIONAL EXCELLENCE FOR ALL STUDENTS

Chapter I The AP Process

- Who Develops the AP Physics Exams?
- How Do They Develop Them?
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- Preparing Students for the Exams
- Teacher Support

This chapter will give you a brief overview of what goes on behind the scenes during the development and grading of the AP Physics Exams. You can find more detailed information in the "Technical Corner" of the AP website (www.collegeboard.org/ap).

Who Develops the AP Physics Exams?

The AP Physics Development Committee, working with physics content experts at Educational Testing Service (ETS), is responsible for creating both the Physics B and Physics C exams. This committee is made up of six teachers, male and female, from secondary schools, colleges, and universities in different parts of the United States. The members provide different perspectives: AP high school teachers offer valuable advice regarding realistic expectations when matters of content coverage, skills required, levels of sophistication, and clarity of phrasing are addressed. On the other hand, college and university faculty members ensure that the questions are at the appropriate level of difficulty for an introductory college course in Physics. Each member typically serves for three years; a person may serve an additional three years as chair of the committee. A list of the members who worked on the 1998 exam is printed on the back cover of this book.

Another person who helps in the development process is the Chief Faculty Consultant (CFC). He or she attends every committee meeting to ensure that the free-response questions selected for the exam can be scored reliably. You can find out more about the role of the CFC, and the scoring process in general, on pages 3 and 4.

How Do They Develop Them?

Committee members individually write exam questions for both the multiple-choice and free-response portions of the exams. They each receive copies of all these draft questions prior to discussing them at a committee meeting. The committee meets twice a year; in the fall, and in the spring. At the fall meeting they begin the development of the exams that will be administered 18 months later.

The development process is different for multiple-choice and free-response sections:

Section I

1. Each committee member independently writes a selection of multiple-choice questions.
2. At the spring meeting, the committee reviews and revises these draft questions. Many of these questions are then tried out on college students enrolled in appropriate physics courses before being used in the AP Exams.
3. Content experts at ETS assemble questions from the pool of multiple-choice items for each exam that complement the free-response questions (see below) in content and skills, so that the total draft exams meet the test specifications.

4. At a subsequent spring meeting, the committee reviews and revises these draft exams.
5. The questions are then typeset, and at the next fall meeting (immediately preceding the administration of the exams in which they will appear), the committee reviews the exams once more before they are printed in the exam booklets.

The committee controls the level of difficulty of the multiple-choice section by including a variety of questions at different levels of difficulty.

Section II

1. Individual committee members write a selection of free-response questions.
2. At the fall meeting, the committee chooses questions for the two exams, and extensively reviews and refines them. They consider, for example, whether the questions will offer an appropriate level of difficulty and whether they will elicit answers that allow faculty consultants to discriminate among the responses along a particular scoring scale. An ideal question enables the stronger students to demonstrate their accomplishments while revealing the limitations of less advanced students.
3. At the spring meeting, the committee reviews and revises the questions once more, then, at the following fall meeting, they give approval to a final draft of all free-response questions, along with the multiple-choice questions.

Question Types

The AP Physics B Exam contains a 90-minute multiple-choice section and a 90-minute free-response section. The Physics C Exam contains two parts, Mechanics and Electricity & Magnetism, each of which receives a separate grade. Each part contains a 45-minute multiple-choice section and a 45-minute free-response section. The two sections are designed to complement each other and to meet the overall course objectives and exam specifications.

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

1. They are highly reliable. Reliability, or the likelihood that candidates of similar ability levels taking a different form of the exam will receive the same scores, is controlled more effectively with multiple-choice questions than with free-response questions.
2. They allow the Development Committee to include a selection of questions at various levels of difficulty, thereby ensuring that the measurement of differences in students' achievement is optimized. For AP Exams, the most important distinctions among students are between those earning the grades of 2 and 3, and 3 and 4. These distinctions are usually best accomplished by using many questions of middle difficulty; that is, questions answered correctly by approximately 40-60% of the students.
3. They allow the CFC to compare the ability level of the current candidates with those from another year. A number of questions from an earlier exam are included in the current one, thereby allowing comparisons to be made between the scores of the earlier group of candidates and the current group. This information, along with other data, is used by the CFC to establish AP grades that reflect the competence demanded by the Advanced Placement Program, and that compare with earlier grades.

Free-response questions on the AP Physics Exams require students to demonstrate a more extended chain of reasoning. Specifically, they:

1. allow candidates to exercise their problem-solving skills;
2. allow students to use their powers of logic and analysis; and
3. permit students to demonstrate their ability to communicate scientific concepts verbally and mathematically.

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

Scoring the Exams

Who Scores the AP Physics Exams?

The people who score the free-response sections of the AP Physics B and Physics C Exams are known as "faculty consultants." These faculty consultants are experienced Physics instructors who either teach the AP course in a high school, or the equivalent course at a college or university. Most have served previously as faculty consultants; 20-25 percent are new each year. Great care is taken to get a broad and balanced group of teachers. Among the factors considered before appointing someone to the role are school locale and setting (urban, rural, etc.), gender, ethnicity, and years of teaching experience. If you are interested in applying to be a faculty consultant at a future AP Reading, you can complete and submit an online application in the "Teacher's Section" of the AP website (www.collegeboard.org/ap), or request a printed application by calling (609) 406-5384.

For the 1998 Physics Reading, the consultants were divided into eight groups, with each group being supervised by an experienced faculty consultant referred to as a table leader. Since the 1998 free-response sections comprised a total of 14 separate questions, each table leader and his or her group of faculty consultants were responsible for the scoring of either one or two questions. Faculty consultants were given initial question assignments based on whether they most commonly taught the B-level or C-level course. At any given time a faculty consultant scored student responses to only a single question. As the Reading progressed, consultants were occasionally re-assigned to different questions in order to complete the grading of the various questions on time and, as nearly as possible, simultaneously.

Ensuring Accuracy

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

How the Scoring Guidelines are Created

1. Before the AP Reading, each table leader prepares a draft of the scoring guidelines for the free-response question(s) for which he or she is responsible.
2. The CFC, table leaders, and ETS content experts meet at the Reading site. They review and revise the draft scoring guidelines, and address possible alternative methods students might use in solving problems, as well as likely common mistakes.
3. When these discussions are completed, each table leader looks through several hundred student responses to the question(s) for which he or she is responsible. During this process, the table leaders select representative student exams which are formed into training packs to be used in acquainting the readers with typical student responses and the application of scoring standards. At this time, the table leader may notice that there is a particular aspect of typical responses that may necessitate modifying the scoring guidelines. Table leaders also select a handful of student responses that exemplify some of the potential difficulties of any scoring standard that may be developed.
4. The table leaders conduct sessions for each of their free-response questions, which are attended by all the faculty consultants in their group. The solutions and draft scoring standards are discussed. Each faculty consultant contributes to the establishment of the final scoring guidelines; if problems or ambiguities become apparent, the scoring guidelines are revised and refined until a final consensus is reached.

Training Faculty Consultants to Apply the Scoring Guidelines

Since the training of the faculty consultants is so vital in ensuring that students receive a grade that accurately reflects their performance, the process is thorough:

1. Groups of faculty consultants provisionally score the training packs of exams formed earlier, and the results of this practice scoring are compared and discussed.
2. Disagreements between these preliminary scorings are used to put final touches on the scoring guidelines.

3. When the table leader is satisfied that the faculty consultants have arrived at a consensus, and that the guideline is being consistently applied, the actual scoring of the exams begins. Faculty consultants are encouraged to seek advice from each other and the table leaders, or the CFC when in doubt about a score. A student response that is problematic receives multiple readings and evaluations.

Maintaining the Scoring Guidelines

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

- Each question is read by a different faculty consultant.
- Exams are shuffled before being formed into packs of 25, so that exams of students from the same school are not read in sequence.
- All scores given by other faculty consultants are completely masked.
- The candidate's identification information is covered.

Using these practices permits each faculty consultant to evaluate free-response answers without being prejudiced by knowledge about individual candidates. Here are some other methods that help ensure that everyone is adhering closely to the scoring guidelines:

- "Spot checks," in which a group of papers is read by two or more faculty consultants in the group, are conducted on a regular basis. These checks allow individual scores to be compared, and provide information on retraining needs.
- Each faculty consultant is asked at least once to rescore a set of selected papers that he or she has already scored, without seeing the previously assigned score. When differences between the original and rescored evaluations occur, the faculty consultant reconsiders the final score, perhaps in consultation with colleagues or the table leader.
- The CFC and the table leaders monitor use of the full range of the scoring scale for the group and for each faculty consultant by checking the results for papers scored multiple times.

Preparing Students for the Exams

The AP Physics B course is a full academic year, algebra-based course covering all major topics in physics. It is comparable to similar introductory survey courses in colleges and universities. The AP Physics C course consists of a semester of Mechanics and a semester of Electricity & Magnetism, both calculus-based. It is comparable to material typically covered in the first two semesters of a three- or four-semester introductory course sequence in colleges and universities.

While some highly motivated students can succeed in studying AP Physics as their first course in physics, in general students should have completed a high-school level course in physics that includes a laboratory component before taking an AP course. For Physics B, they should have completed mathematics courses that include algebra, geometry, and trigonometry. For Physics C, students should also have studied or be concurrently enrolled in a calculus course.

The AP Physics course should allow students to develop their understanding of the concepts of physics. This includes use of a variety of ways of expressing these concepts: verbal, mathematical, and graphical. They should also develop their skills in solving problems analytically (expressing answers in both symbolic and numeric forms), constructing and interpreting graphs, and writing explanations to show their reasoning or justify their answers. A more detailed list of skills appropriate to the study of physics that are assessed by the exams can be found on pages 7-8 and pages 117-118. This list includes laboratory skills. Introductory college-level physics courses include a lab component, and it is important that AP Physics students have an appropriate lab experience if the course is to be comparable to college courses. A student who has developed the skills included in these lists will be well prepared for their future studies, whether or not these plans include additional study of physics.

Teacher Support

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

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

AP's corner of College Board Online (www.collegeboard.org/ap). You can supplement your AP course and preparation for the exam with advice and resources from our AP web pages. Check out the "Teacher's Corner" and the "Students' and Parents' Channel."

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

AP publications and videos. See the Appendix for descriptions of a variety of useful materials for teachers. Of particular interest are two publications that complement this *Released Exam* — the *Packet of 10 1998 AP Physics B Examinations* and the *Packet of 10 1998 AP Physics C Examinations*. Teachers can use these multiple copies of the 1998 exams, which come with blank answer sheets, to simulate a national administration in their classroom.

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

Chapter II The 1998 AP Physics B Examination

- Exam Content and Format
- Giving a Practice Exam
- Instructions for Administering the Exam
- The Exam

Exam Content and Format

The Physics B Examination covers material at the level of an introductory survey course that does not use calculus. It is three hours long and is divided equally in time between a 70-question multiple-choice section and a free-response section. The two sections are weighted equally, and a single grade is reported. A student is expected to spend about 10 or 15 minutes answering each free-response question, depending on the length of the question. For the 1998 examination, there were two free-response questions with a suggested time of 15 minutes, and six with a suggested time of 10 minutes.

The percentages to be devoted to each major category are as follows. A more detailed outline can be found in the AP Physics Course Description.

Content Area	Percentage Goals for Physics B exam
I. Newtonian Mechanics	35%
A. Kinematics	7%
B. Newton's laws of motion	9%
C. Work, energy, power	5%
D. Systems of particles, liner momentum	4%
E. Circular motion and rotation	4%
F. Oscillations and gravitation	6%
II. Thermal Physics	10%
A. Temperature and heat	3%
B. Kinetic theory and thermodynamics	7%
III. Electricity and Magnetism	25%
A. Electrostatics	5%
B. Conductors, capacitors, dielectrics	4%
C. Electric circuits	7%
D. Magnetostatics	4%
E. Electromagnetism	5%
IV. Waves and Optics	15%
A. Wave motion (including sound)	5%
B. Physical optics	5%
C. Geometric optics	5%
V. Atomic and Nuclear Physics	15%
A. Atomic physics and quantum effects	10%
B. Nuclear physics	5%

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

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

Departures from these percentages in the free-response sections in any given year are compensated for in the multiple-choice sections so that the overall topic distribution for the entire examination is achieved as closely as possible, although it may not be reached exactly.

The examination is designed to test students' ability to interpret and apply their knowledge of physics both qualitatively and quantitatively. The multiple-choice section of the examination 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.

In grading the free-response sections, credit for the answers depends on the quality of the solutions and explanations given, so students should show their work. If students make a mistake, they may cross out or erase it. Crossed-out work will not be graded. Credit may be lost for incorrect work that is not crossed out.

The complete examination is designed to provide the maximum information about differences in students' achievement in physics. Therefore, it is intended that the average scores be about 50 percent of the maximum possible scores for each multiple-choice and free-response section. Thus, students should be aware that they may find these examinations more difficult than most classroom examinations. However, it is possible for students who have studied most but not all topics in the outline to obtain acceptable grades.

The International System (SI) of units is used predominantly in the examination. The use of rulers or straightedges is permitted on the free-response section to facilitate the sketching of graphs or diagrams that might be required. Calculators are not permitted on the multiple-choice section. They are allowed on the free-response section. Any programmable or graphing calculator may be used except for those with typewriter-style (QWERTY) keyboards, and memories do not have to be cleared. Calculators cannot be shared with other students. Also, tables containing commonly used physics equations are printed on the green insert (pages 40-42) provided with each examination for students to use when taking the free-response section. These equations are not permitted for the multiple-choice section. (This policy is subject to change; see the current AP Physics Course Description for the policy pertaining to the present year's examination.)

Giving a Practice Exam

The following pages contain the instructions, as printed in the 1998 *Coordinator's Manual*, for administering the AP Physics B and Physics C Exams. Following these instructions is a copy of the 1998 Physics B exam. If you wish to use this released exam to test your students, you may wish to use the instructions to create an exam situation that closely resembles a national administration. If so, read only the directions in the boxes to the students; all other instructions are for the person administering the text and need not be read aloud. Some instructions, such as those referring to the date, the time, and page numbers, are no longer relevant; please ignore them.

Another publication that you might find useful is the so-called "Packet of 10." They are just that: packets of ten of the 1998 AP Physics B Exam, and blank answer sheets. For ordering information, see the back of this book.

DO NOT USE THESE INSTRUCTIONS FOR A LATE ADMINISTRATION. Use the separate instructions enclosed with the alternate exams.

IMPORTANT: For the AP Physics examinations, students are permitted to use scientific, programmable, or graphing calculators ON SECTION II ONLY. Students may NOT have calculators on their desks during the administration of Section I. Calculators with QWERTY keyboards are not allowed. Calculators with infrared capabilities are permitted; however, since data can be exchanged between these calculators if they are aligned and very close together, proctors should ensure that students keep their calculators sufficiently far apart and that calculators' infrared ports are not facing each other. **Before starting the exam administration**, make sure no student has a calculator with the features that are not permitted. If a candidate has such a calculator, give the candidate a calculator from your supply. If a candidate does not want to use the calculator you have provided, have him or her write, date, and sign the statement in the Calculators for Chemistry and Physics subheading under "Calculators" on page 16.

Make sure candidates do not share calculators during the examination.

READ CAREFULLY ALL THE FOLLOWING INSTRUCTIONS WELL IN ADVANCE OF THE ADMINISTRATION.

Examinees may exercise different options; they may be taking the **entire** B Examination, the **entire** C Examination, Mechanics **only** of the C Examination, or Electricity and Magnetism **only** of the C Examination. Before giving the exams, determine which options will be exercised by each candidate.

If only the B Examination is to be given, follow the instructions for giving the B Examination labeled (B).

If only the C Examination is to be given, follow the instructions for giving the C Examination labeled (C) on page 105. These instructions also include instructions for administering Mechanics only and Electricity and Magnetism only.

If both the B Examination and either or both parts of the C Examination are to be given, you should arrange, if possible, for the B and C Examinations to take place in separate rooms, so only one set of instructions needs to be followed in each room.

If this is not possible, you should separate those taking the B Exam from those taking the C Exam in the testing room in order to facilitate following both sets of instructions. In this case, you may wish to start one set of candidates first, before instructions are read to the other group, a procedure that requires two watches since the two sets of candidates will start and finish at different times. Or you may wish to read the instructions for one examination, asking the candidates taking that examination to wait until the instructions for the other examination are read. That way both sets of candidates can begin and end at the same time, so only a single watch is needed.

(B) Instructions for Giving the Physics B Examination

Make sure you have completed the general instructions beginning on page 27.

——AT ALL ADMINISTRATIONS, SAY:——

It is Thursday afternoon, May 14, and you will be taking the AP Physics B Exam. Put your calculators under your chairs now. No calculators are allowed for this section of the examination. . . . Print your name, last name first, on the front cover of the unsealed Section I booklet and read the directions on the back cover of the booklet. When you have finished, look up. . . .

Work only on Section I until time is called. You are not to open the sealed Section II booklet until you are told to do so. Scratch paper is not allowed, but you may use the margins of your Section I booklet. Remember, when you come to the end of the multiple-choice questions, there will be answer ovals left on your answer sheet.

When I tell you, open your Section I booklet and begin. Near the front of the Section I booklet, you will find a table of information that may be helpful. Are there any questions?

Answer all questions regarding procedure. Set your watch at 12:59. When it reads exactly 1:00, say:

Begin work on Section I.

While the candidates are working on Section I, you and your proctors should make sure they are marking answers on their answer sheets in pencil and are not looking at their Section II booklets.

——AT 2:30——

Stop working. Turn to page 20 in your Section I booklet. Answer questions 101 through 107. These are survey questions and will not influence your examination grade. You may not go back at this time to work on any of the previous questions.

To help you and your proctors make sure students do not work on any other part of the examination, the two pages containing the survey questions are identified with a large S on the upper outside corner of each page.

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

> **Close your Section I booklet and keep it closed on your desk. Make sure you printed your name on the front cover of your booklet. . . . Do not insert your answer sheet in the booklet. I will now collect the answer sheets.**

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

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

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

GIVE YOUR BREAK INSTRUCTIONS.

After the break, say:

> **You may now place your calculators on your desks. Open the package containing your Section II booklet. Turn to the back cover of the booklet, and read the instructions at the upper left. . . . Print your identification information, in pen or pencil, in the boxes. . . . Taking care not to tear the sheet beneath the cover, detach the perforation at the top. . . . Fold the flap down, and moisten and press the glue strip firmly along the entire lower edge. . . . Your identification information should now be covered and will not be known by those scoring your answers.**
>
> **Read the instructions at the upper right of the back cover. Print your initials in the three boxes provided. . . . Next, take two AP number labels from your Candidate Pack and place them in the two boxed areas, one below the instructions and one to the left. If you don't have number labels left, copy your number from the back cover of your Candidate Pack within both of the boxed areas.**
>
> **. . . Item 6 provides you with the option of giving permission to Educational Testing Service to use your free-response materials for educational research and instructional purposes. Your name would not be used in connection with the free-response materials. Read the statement and answer either "yes" or "no." . . . Are there any questions?**

Answer all questions regarding procedure. Then say:

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

Collect the Candidate Packs. Then say:

> **Read the directions for Section II on the back of your booklet. Look up when you have finished. . . . If you need more paper, raise your hand. Are there any questions?**

Answer all questions regarding procedure. Set your watch at 2:29. When it reads exactly 2:30, say:

> **Open the Section II booklet and turn to the center of the booklet. Tear out the insert. . . . You may use the insert for notes, but write all your answers in the Section II booklet, in the spaces provided after each part. Print your name, teacher, and school in the upper left-hand corner of the insert. I will be collecting this insert at the end of the administration. It will be returned to you at a later date by your teacher. Begin work on Section II.**

You and your proctors should check to be sure all candidates are writing their answers in the Section II booklets. Communication between calculators is prohibited during the exam. Proctors should walk around and ensure that calculators' infrared ports are not facing each other.

——AT 4:00——

> **Stop working. Close your Section II booklet and keep it closed on your desk. I will now collect your booklets. Remain in your seats, without talking, while the exam materials are being collected.**

Collect the Section II booklets and green inserts. Be sure you have one from every candidate. Check the back of each booklet to make sure the candidate's AP number appears in the two boxes. The green inserts may be given to the appropriate teacher for return to the students 48 hours after the administration.

Fill in the necessary information for the Physics B Examination on the S&R Form. Put the exam materials in locked storage until they are returned to ETS in one shipment after your school's last administration. See "Activities After the Exam."

C Instructions for Giving the Physics C Examination

To help you and your proctors make sure students work on the correct parts of the Physics C Examination, the parts are identified as follows. The Mechanics parts of Sections I and II have a line of **M**'s across the top of each page. The Electricity and Magnetism parts of Sections I and II have a line of **E**'s. The two pages containing the survey questions have a large **S** on the upper outside corner of each page.

Make sure you have completed the general instructions beginning on page 27.

IF ALL CANDIDATES ARE TAKING MECHANICS ONLY OR ELECTRICITY AND MAGNETISM ONLY, GO TO PAGE 107 AND START WITH THE INSTRUCTIONS MARKED WITH AN ASTERISK(*).

IF SOME CANDIDATES ARE TAKING MECHANICS ONLY OR ELECTRICITY AND MAGNETISM ONLY, AND SOME ARE TAKING THE ENTIRE C EXAMINATION, GO TO PAGE 108 AND START WITH THE INSTRUCTIONS MARKED WITH A DAGGER (†).

IF ALL CANDIDATES ARE TAKING THE ENTIRE C EXAMINATION, START HERE AND SAY:

It is Thursday afternoon, May 14, and you will be taking the AP Physics C Exam. Put your calculators under your chairs. No calculators are allowed for this section of the examination. Print your name, last name first, on the front cover of the unsealed Section I booklet and read the directions on the back cover of the booklet. When you have finished, look up. . . .

You will work only on Section I, Mechanics (pages 4-14 of the C Examination) for the first 45 minutes.

You are not to open your sealed Section II booklet until you are told to do so. Scratch paper is not allowed, but you may use the margins of your Section I booklet. Remember, when you come to the end of the multiple-choice questions, there will be answer ovals left on your answer sheet.

When I tell you, open your Section I booklet and begin. Near the front of the Section I booklet, you will find a table of information that may be helpful throughout the examination. Are there any questions?

Answer all questions regarding procedure. Set your watch at 12:59. When it reads exactly 1:00, say:

Begin work on Section I.

While the candidates are working on Section I, you and your proctors should make sure they are marking answers on their answer sheets in pencil and are not looking at their Section II booklets.

——AT 1:45——

Stop working. Close your Section I booklet and keep it closed on your desk. You will work only on the multiple-choice questions in Section I, Electricity and Magnetism (pages 16-26 of the C Examination), during the next 45 minutes. Do not start until I tell you to do so. Your calculators should remain under your chair. No calculators are permitted for this section of the examination.

Answer all questions regarding procedure. Set your watch at 1:44. When it reads exactly 1:45, say:

Begin working.

——AT 2:30——

Stop working.

Candidates should now be instructed to answer the survey questions on pages 28-29 of the Section I booklet. Say:

Turn to page 28 of the Section I booklet and answer questions 101 through 107. These are survey questions and will not affect your examination grade. You may not go back at this time to work on any of the previous questions.

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

Close your Section I booklet and keep it closed on your desk.

Make sure you have printed your name, last name first, on the front cover of your Section I booklet. . . . Do *not* insert your answer sheet in the booklet. I will now collect the answer sheets.

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

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

Collect the sealed Section I exam booklets. Be sure you have one from each candidate.

When these exam materials have been collected, give your break instructions (see "Breaks During the Examination"). The break should be a maximum of five minutes. Say:

You will now have a five-minute break.

After the break, say:

You may use your calculator for Section II of the examination. Place your calculator on the desk. Open the package containing your Section II booklet. Turn to the back cover of the Section II booklet, and read the instructions at the upper left. . . . Using either a ballpoint pen or a pencil, print your identification information in the boxes. . . . Taking care not to tear the sheet beneath the cover, detach the perforation at the top. . . . Fold the flap down, and moisten and press the glue strip firmly along the entire lower edge. . . . Your identification information should now be covered and will not be known by those scoring your answers.

Read the instructions at the upper right of the back cover. Print your initials in the three boxes provided. . . . Next, take two AP number labels from your Candidate Pack and place them in the two boxed areas, one below the instructions and one to the left. If you don't have number labels left, copy your number from the back cover of your Candidate Pack within both of the boxed areas. . . . Item 6 provides you with the option of giving permission to Educational Testing Service to use your free-response materials for educational research and instructional purposes. Your name would not be used in connection with the free-response materials. Read the statement and answer either "yes" or "no." . . . Are there any questions?

Answer all questions regarding procedure. Then say:

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

Collect the Candidate Packs. Then say:

Read the directions for Section II on the back of your booklet. Mark the box on the back cover indicating you are taking Mechanics as well as Electricity and Magnetism. Look up when you have finished. . . . If you need more paper, raise your hand. You are to work only on the Mechanics questions on pages 4-15 during the next 45 minutes. Are there any questions?

Answer all questions regarding procedure. Set your watch at 2:29. When it reads exactly 2:30, say:

Open the Section II booklet and turn to the center of the booklet. Tear out the insert. . . . You may use the insert for notes, but write all your answers in the Section II booklet, in the spaces provided after each part. Print your name, teacher, and school in the upper left-hand corner of the insert. I will be collecting the insert at the end of the administration. It will be returned to you at a later date by your teacher. Begin work on Section II.

You and your proctors should check to be sure all candidates are writing their answers in the Section II booklets. Communication between calculators is not permitted during the exam. Proctors should walk around and make sure calculators' infrared ports are not facing each other.

——AT 3:15——

Stop working on Mechanics and begin work on Electricity and Magnetism, pages 16-25.

——AT 4:00——

Stop working. Close your booklet and keep it closed on your desk. I will now collect the Section II booklets and green inserts. Remain in your seats, without talking, while the exam materials are being collected.

Collect the Section II booklets and green inserts. Be sure you have one from every candidate. Check the back of each booklet to make sure the candidate's AP number appears in the two boxes.

For all Section II booklets collected, make certain the box on the back cover is marked indicating the candidate took both Mechanics and Electricity and Magnetism.

The green inserts may be given to the appropriate teacher for return to the students 48 hours after the administration.

Fill in the necessary information for the Physics C Examination on the S&R Form. Put the exam materials in locked storage until they are returned to ETS in one shipment after your school's last administration. See "Activities After the Exam."

✻ IF ALL CANDIDATES ARE TAKING MECHANICS ONLY OR ELECTRICITY AND MAGNETISM ONLY, START HERE AND SAY:

It is Thursday afternoon, May 14, and you will be taking the AP Physics C Exam. Put your calculators under your chairs. No calculators are allowed for this section of the examination. Print your name, last name first, on the front cover of the unsealed Section I booklet and read the directions on the back cover of the booklet. When you have finished, look up. . . .

If you are taking Mechanics only, you will work only on Section I, Mechanics (pages 4-14 of the C Examination) for the first 45 minutes.

If you are taking Electricity and Magnetism only, you will work on Section I, Electricity and Magnetism (pages 16-26 of the C Examination) for the first 45 minutes.

You are not to open your sealed Section II booklet until you are told to do so. Scratch paper is not allowed, but you may use the margins of your Section I booklet. Remember, when you come to the end of the multiple-choice questions, there will be answer ovals left on your answer sheet.

When I tell you, open your Section I booklet and begin. Near the front of the Section I booklet, you will find a table of information that may be helpful throughout the examination. Are there any questions?

Answer all questions regarding procedure. Set your watch at 12:59. When it reads exactly 1:00, say:

Begin work on Section I.

While the candidates are working on Section I, you and your proctors should make sure they are marking answers on their answer sheets in pencil and are not looking at their Section II booklets.

——AT 1:45——

Stop working.

Please turn to page 28 of the Section I booklet and answer questions 101 through 107. These are survey questions and will not affect your examination grade. You may not go back at this time to work on any of the previous questions.

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

Close your Section I booklet and keep it closed on your desk.

Make sure you have printed your name, last name first, on the front cover of your Section I booklet. . . . Do not insert your answer sheet in the booklet. I will now collect the answer sheets.

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

Seal your Section I booklets with the three seals provided. Pull off each seal from the backing sheet and press it on the front cover so it just covers the area marked "PLACE SEAL HERE." Fold it over the open edge and press it to the back cover. Use one seal for each open edge. Be careful not to let the seals touch anything except the marked areas. . . . You may stretch now, but do not talk while the materials are being collected.

Collect the sealed Section I exam booklets. Be sure you receive one from each candidate. When all materials have been collected, say:

Open the package containing your Section II booklet. Turn to the back cover of the Section II booklet, and read the instructions at the upper left. . . . Print your identification information, in pen or pencil, in the boxes. . . . Taking care not to tear the sheet beneath the cover, detach the perforation at the top. . . . Fold the flap down, and moisten and press the glue strip firmly along the entire lower edge. . . . Your identification information should now be covered and will not be known by those scoring your answers.

Read the instructions at the upper right of the back cover. Print your initials in the three boxes provided. . . . Next, take two AP number labels from your Candidate Pack and place them in the two boxed areas, one below the instructions and one to the left. If you don't have number labels left, copy your number from the back cover of your Candidate Pack within both of the boxed areas. . . . Item 6 provides you with the option of giving permission to Educational Testing Service to use your free-response materials for educational research and instructional purposes. Your name would not be used in connection with the free-response materials. Read the statement and answer either "yes" or "no.". . . Are there any questions?

Answer all questions regarding procedure. Then say:

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

Collect the Candidate Packs. Then say:

You may use your calculator for Section II of the examination. Place your calculator on the desk. Read the directions for Section II on the back cover of your sealed booklet. Mark one of the boxes on the back cover to indicate which examination you are taking. Look up when you have finished. . . . If you need more paper, raise your hand. The Section II Mechanics questions are on pages 4-15, and the Section II Electricity and Magnetism questions are on pages 16-25. Are there any questions?

Answer all questions regarding procedure. Set your watch at 1:44. When it reads exactly 1:45, say:

Open the Section II booklet and turn to the center of the booklet. Tear out the insert. . . . You may use the insert for notes, but write all your answers in the Section II booklet, in the spaces provided after each part. Print your name, teacher, and school in the upper left-hand corner of the insert. I will be collecting this insert at the end of the administration. It will be returned to you at a later date by your teacher. Begin work on Section II.

You and your proctors should check to be sure all candidates are writing their answers in the Section II booklets. Communication between calculators is not permitted during the exam. Proctors should walk around and make sure calculators' infrared ports are not facing each other.

——AT 2:30——

Stop working and close your examination booklets. Please remain seated. I will now collect your Section II booklet and green insert.

Collect the Section II booklets and green inserts.

Check the back of each booklet to make sure the candidate's AP number appears in the two boxes; also make certain the appropriate box indicating which Physics C Exam the candidate took has been checked. The green inserts may be given to the appropriate teacher 48 hours after the administration.

Fill in the necessary information for the Physics C Examination on the S&R Form. Put the exam materials in locked storage until they are returned to ETS in one shipment after your school's last administration. See "Activities After the Exam."

FOR CANDIDATES WHO ARE TAKING MECHANICS ONLY OR ELECTRICITY AND MAGNETISM ONLY ALONG WITH CANDIDATES WHO ARE TAKING THE ENTIRE C EXAM, START HERE AND SAY:

It is Thursday afternoon, May 14, and you will be taking the AP Physics C Exam. Put your calculators under your chairs. No calculators are allowed for this section of the examination. Print your name, last name first, on the front cover of the unsealed Section I booklet and read the directions on the back cover of the booklet. When you have finished, look up. . . .

If you are taking the entire C Examination or Mechanics only, you will work only on Section I, Mechanics (pages 4-14 of the C Examination) for the first 45 minutes.

If you are taking Electricity and Magnetism only, you will work on Section I, Electricity and Magnetism (pages 16-26 of the C Examination) for the first 45 minutes.

You are not to open your sealed Section II booklet until you are told to do so. Scratch paper is not allowed, but you may use the margins of your Section I booklet. Remember, when you come to the end of the multiple-choice questions, there will be answer ovals left on your answer sheet.

When I tell you, open your Section I booklet and begin. Near the front of the Section I booklet, you will find a table of information that may be helpful throughout the examination. Are there any questions?

Answer all questions regarding procedure. Set your watch at 12:59. When it reads exactly 1:00, say:

Begin work on Section I.

While the candidates are working on Section I, you and your proctors should make sure they are marking answers on their answer sheets in pencil and are not looking at their Section II booklets.

——AT 1:45——

Stop working. If you are taking the entire C examination, close your Section I booklet and keep it closed on your desk. Please sit quietly while instructions are being given to candidates who are taking Mechanics only or Electricity and Magnetism only.

Candidates who are taking Mechanics only or Electricity and Magnetism only should now be instructed to answer the survey questions on pages 28-29 of the Section I booklet. Say:

If you are taking Mechanics only or Electricity and Magnetism only, turn to page 28 of the Section I booklet and answer questions 101 through 107. These are survey questions and will not affect your examination grade. You may not go back at this time to work on any of the previous questions.

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

Close your Section I booklet and keep it closed on your desk.

If you are taking Mechanics only or Electricity and Magnetism only, make sure you have printed your name, last name first, on the front cover of your Section I booklet. . . . Do *not* insert your answer sheet in the booklet. I will now collect your answer sheets.

After you have collected an answer sheet from these candidates, say:

If I have just collected your answer sheet, seal your Section I booklets with the three seals provided. Pull off each seal from the backing sheet and press it on the front cover so it just covers the area marked "PLACE SEAL HERE." Fold it over the open edge and press it to the back cover. Use one seal for each open edge. Be careful not to let the seals touch anything except the marked areas.

Collect the sealed Section I exam booklets. Be sure you have one from each candidate.

If you are taking Mechanics only or Electricity and Magnetism only you will be working on Section II for the next 45 minutes. You may use your calculator for Section II of the examination. Place your calculators on the desk. Open the package containing your Section II booklet. Turn to the back cover of the Section II booklet, and read the instructions at the upper left. . . . Using either a ballpoint pen or a pencil, print your identification information in the boxes. . . . Taking care not to tear the sheet beneath the cover, detach the perforation at the top. . . . Fold the flap down, and moisten and press the glue strip firmly along the entire lower edge. . . . Your identification information should now be covered and will not be known by those scoring your answers.

Read the instructions at the upper right of the back cover. Print your initials in the three boxes provided. . . . Next, take two AP number labels from your Candidate Pack and place them in the two boxed areas, one below the instructions and one to the left. If you don't have number labels left, copy your number from the back cover of your Candidate Pack within both of the boxed

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

Answer all questions regarding procedure. Then say:

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

Collect the Candidate Packs. Then say:

Read the directions for Section II on the back of your booklet. Mark one of the boxes on the back cover to indicate which exam you are taking. Look up when you have finished. . . . If you need more paper, raise your hand. The Section II Mechanics questions are on pages 4-15 and the Electricity and Magnetism questions are on pages 16-25. Are there any questions?

Answer all questions regarding procedure. Then say:

When I tell you to begin, open the Section II booklet and turn to the center of the booklet. Tear out the insert. . . . You may use the insert for notes, but write all your answers in the Section II booklet, in the spaces provided after each part. Print your name, teacher, and school in the upper left-hand corner of the insert. I will be collecting the insert at the end of the administration. It will be returned to you at a later date by your teacher. If you are taking the entire exam, you will work only on the multiple-choice questions in Section I, Electricity and Magnetism (pages 16-21 of the C Examination), during the next 45 minutes. Do not start until I tell you to do so. Your calculators should remain under your chair. No calculators are permitted for this section of the examination.

Answer all questions regarding procedure. Set your watch at 1:44. When it reads exactly 1:45, say:

Begin working.

——AT 2:30——

Stop working. If you are taking Mechanics only or Electricity and Magnetism only, close your booklets and keep them closed on your desk.

Candidates who are taking the entire exam should now be instructed to answer the survey questions on pages 28-29 of the Section I booklet. Say:

If you are taking the entire C exam, turn to page 28 of the Section I booklet and answer questions 101 through 107. These are survey questions and will not affect your examination grade. You may not go back at this time to work on any of the previous questions.

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

Close your Section I booklet and keep it closed on your desk.

Make sure you have printed your name, last name first, on the front cover of your Section I booklet. . . . Do *not* insert your answer sheet in the booklet. I will now collect the answer sheets.

After you have collected an answer sheet each candidate, say:

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

Collect the sealed Section I exam booklets. Be sure you have one from each candidate.

When these exam materials have been collected, ONLY STUDENTS TAKING THE ENTIRE EXAM WILL HAVE A BREAK. The students taking Mechanics only or Electricity and Magnetism only must remain seated during the break, and must not be allowed to talk to the students who receive the break. Give your break instructions (see "Breaks During the Examination"). The break should be a maximum of five minutes. Say:

Students who are taking the entire exam will now have a five-minute break. Students who are taking Mechanics only or Electricity and Magnetism only must remain seated until the other students have returned from their break. I will now collect your Section II booklets and green inserts. Remain in your seats, without talking, while the exam materials are being collected.

Collect the Section II booklets and green inserts. Be sure you have one from each candidate. Check the back of each booklet to make sure the candidate's AP number appears in the two boxes.

For all Section II booklets collected, make certain the box on the back cover is marked indicating whether the candidate took Mechanics or Electricity and Magnetism.

When all students have returned from the break, you should dismiss candidates who are taking Mechanics only or Electricity and Magnetism only.

After the break, say:

You may use your calculator for Section II of the examination. Place your calculators on the desk. Open the package containing your Section II booklet. Turn to the back cover of the Section II booklet, and read the instructions at the upper left. . . . Using either a ballpoint pen or a pencil, print your identification information in the boxes. . . . Taking care not to tear the sheet beneath the cover, detach the perforation at the top. . . . Fold the flap down, and moisten and press the glue strip firmly along the entire lower edge. . . . Your identification information should now be covered and will not be known by those scoring your answers.

Read the instructions at the upper right of the back cover. Print your initials in the three boxes provided. . . . Next, take two AP number labels from your Candidate Pack and place them in the two boxed areas, one below the instructions and one to the left. If you don't have number labels left, copy your number from the back cover of your Candidate Pack within both of the boxed areas. . . . Item 6 provides you with the option of giving permission to Educational Testing Service to use your free-response materials for educational research and instructional purposes. Your name would not be used in connection with the free-response materials. Read the statement and answer either "yes" or "no." . . . Are there any questions?

Answer all questions regarding procedure. Then say:

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

Collect the Candidate Packs. Then say:

Read the directions for Section II on the back of your booklet. Mark the box on the back cover indicating you are taking Mechanics as well as Electricity and Magnetism. Look up when you have finished. . . . If you need more paper, raise your hand. You are to work only on the Mechanics questions on pages 4-15 during the next 45 minutes. Are there any questions?

Answer all questions regarding procedure. Set your watch at 2:29. When it reads exactly 2:30, say:

Open the Section II booklet and turn to the center of the booklet. Tear out the insert. . . . You may use the insert for notes, but write all your answers in the Section II booklet, in the spaces provided after each part. Print your name on the upper left-hand corner of the insert. I will be collecting the insert at the end of the administration. It will be returned to you at a later date by your teacher. Begin work on Section II.

You and your proctors should check to be sure all candidates are writing their answers in the Section II booklets. Communication between calculators is not permitted during the exam. Proctors should walk around and make sure calculators' infrared ports are not facing each other.

——AT 3:15——

Stop working on Mechanics and begin work on Electricity and Magnetism, pages 16-25.

——AT 4:00——

Stop working. Close your booklet and keep it closed on your desk. I will now collect the Section II booklets and green inserts. Remain in your seats, without talking, while the exam materials are being collected.

Collect the Section II booklets and green inserts. Be sure you have one from every candidate. Check the back of each booklet to make sure the candidate's AP number appears in the two boxes.

For all Section II booklets collected, make certain the box on the back cover is marked indicating the candidate took both Mechanics and Electricity and Magnetism.

The green inserts may be given to the appropriate teacher for return to the students 48 hours after the administration.

Fill in the necessary information for the Physics C Examination on the S&R Form. Put the exam materials in locked storage until they are returned to ETS in one shipment after your school's last administration. See "Activities After the Exam."

PHYSICS B

You must take the entire B Exam as follows:

First 90 minutes	Section I — Multiple Choice 70 Questions This booklet, pp. 3-19 No calculators allowed Percent of Total Grade — 50
2-minute interval	Survey Questions 7 Questions (101-107) This booklet, pp. 20-21
Second 90 minutes	Section II — Free Response 8 Questions Pink Booklet, pp. 4-20 Any battery-operated, hand-held calculator allowed Percent of Total Grade — 50

Each multiple-choice question has equal weight. Rulers or straightedges may be used in both sections. However, calculators may be used in Section II only, NOT in Section I. Calculators may not be shared. A table of information that may be helpful is found on page 2 of this book.

Section I of this examination contains 70 multiple-choice questions. Therefore, please be careful to fill in only the ovals that are preceded by numbers 1 through 70 on your answer sheet. Also, please be careful to fill in the ovals preceded by the numbers 101 through 107 when answering the survey questions.

General Instructions

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

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

Example:

Chicago is a

(A) state
(B) city
(C) country
(D) continent
(E) village

Sample Answer



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

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

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TABLE OF INFORMATION FOR 1998

CONSTANTS AND CONVERSION FACTORS

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

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 examination.

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. The work done by a thermodynamic system is defined as a positive quantity.

PHYSICS B

SECTION I

Time—90 minutes

70 Questions

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

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

1. A solid metal ball and a hollow plastic ball of the same external radius are released from rest in a large vacuum chamber. When each has fallen 1 m, they both have the same

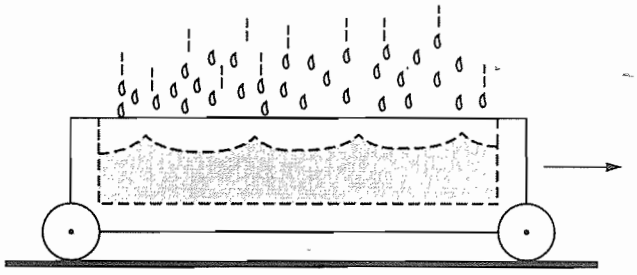
   (A) inertia
   (B) speed
   (C) momentum
   (D) kinetic energy
   (E) change in potential energy

2. A student weighing 700 N climbs at constant speed to the top of an 8 m vertical rope in 10 s. The average power expended by the student to overcome gravity is most nearly

   (A) 1.1 W
   (B) 87.5 W
   (C) 560 W
   (D) 875 W
   (E) 5,600 W

3. A railroad car of mass m is moving at speed v when it collides with a second railroad car of mass M which is at rest. The two cars lock together instantaneously and move along the track. What is the speed of the cars immediately after the collision?

   (A) $\frac{v}{2}$
   (B) $\frac{mv}{M}$
   (C) $\frac{Mv}{m}$
   (D) $\frac{(m + M)v}{m}$
   (E) $\frac{mv}{m + M}$



4. An open cart on a level surface is rolling without frictional loss through a vertical downpour of rain, as shown above. As the cart rolls, an appreciable amount of rainwater accumulates in the cart. The speed of the cart will

   (A) increase because of conservation of momentum
   (B) increase because of conservation of mechanical energy
   (C) decrease because of conservation of momentum
   (D) decrease because of conservation of mechanical energy
   (E) remain the same because the raindrops are falling perpendicular to the direction of the cart's motion

5. Units of power include which of the following?

   I. Watt
   II. Joule per second
   III. Kilowatt-hour

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

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6. A 2 kg object moves in a circle of radius 4 m at a constant speed of 3 m/s. A net force of 4.5 N acts on the object. What is the angular momentum of the object with respect to an axis perpendicular to the circle and through its center?

(A) $9\frac{\text{N}\cdot\text{m}}{\text{kg}}$

(B) $12\frac{\text{m}^2}{\text{s}}$

(C) $13.5\frac{\text{kg}\cdot\text{m}^2}{\text{s}^2}$

(D) $18\frac{\text{N}\cdot\text{m}}{\text{kg}}$

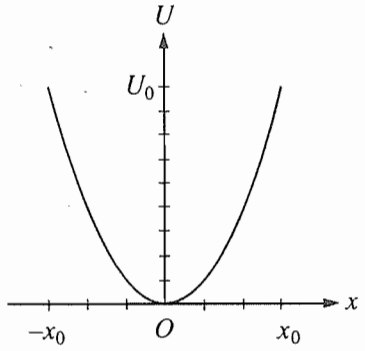
(E) $24\frac{\text{kg}\cdot\text{m}^2}{\text{s}}$

7. Three forces act on an object. If the object is in translational equilibrium, which of the following must be true?

I. The vector sum of the three forces must equal zero.
II. The magnitudes of the three forces must be equal.
III. All three forces must be parallel.

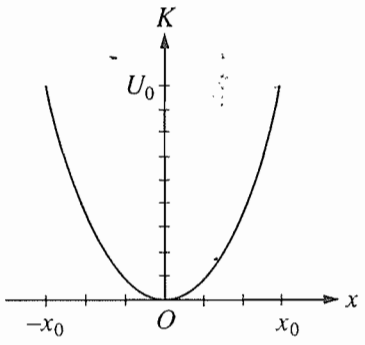
(A) I only
(B) II only
(C) I and III only
(D) II and III only
(E) I, II, and III

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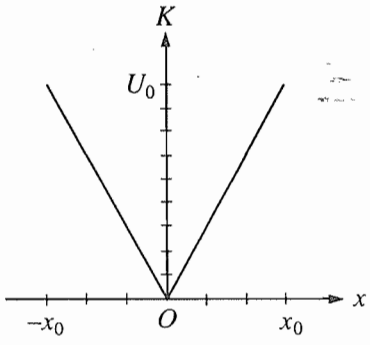


8. The graph above represents the potential energy U as a function of displacement x for an object on the end of a spring oscillating in simple harmonic motion with amplitude x_0. Which of the following graphs represents the kinetic energy K of the object as a function of displacement x ?

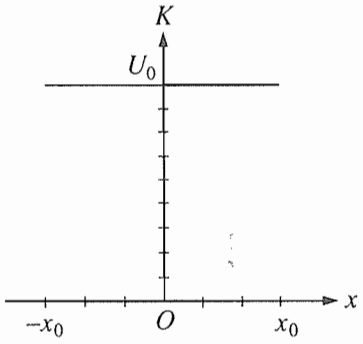
(A)



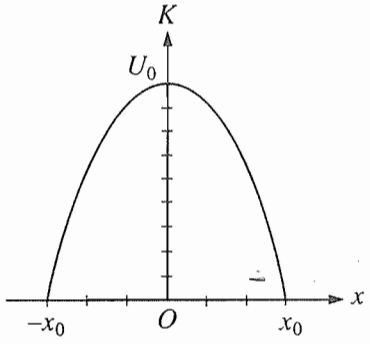
(B)



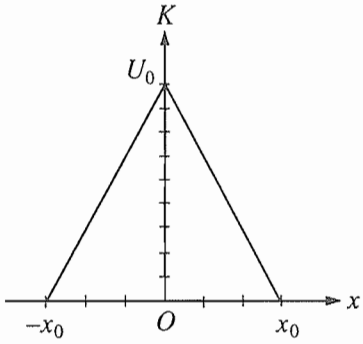
(C)



(D)



(E)



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9. A child pushes horizontally on a box of mass m which moves with constant speed v across a horizontal floor. The coefficient of friction between the box and the floor is μ. At what rate does the child do work on the box?

(A) μmgv
(B) mgv
(C) $v/\mu mg$
(D) $\mu mg/v$
(E) μmv^2

10. Quantum transitions that result in the characteristic sharp lines of the X-ray spectrum always involve

(A) the inner electron shells
(B) electron energy levels that have the same principal quantum number
(C) emission of beta particles from the nucleus
(D) neutrons within the nucleus
(E) protons within the nucleus

11. Which of the following experiments provided evidence that electrons exhibit wave properties?

I. Millikan oil-drop experiment
II. Davisson-Germer electron-diffraction experiment
III. J. J. Thomson's measurement of the charge-to-mass ratio of electrons

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

12. Quantities that are conserved in all nuclear reactions include which of the following?

I. Electric charge
II. Number of nuclei
III. Number of protons

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

13. Which of the following is true about the net force on an uncharged conducting sphere in a uniform electric field?

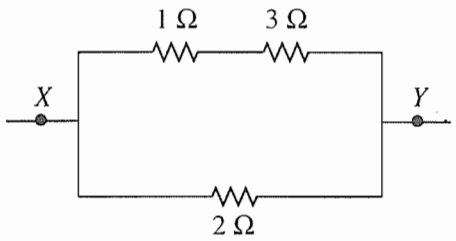
(A) It is zero.
(B) It is in the direction of the field.
(C) It is in the direction opposite to the field.
(D) It produces a torque on the sphere about the direction of the field.
(E) It causes the sphere to oscillate about an equilibrium position.

14. Two parallel conducting plates are connected to a constant voltage source. The magnitude of the electric field between the plates is 2,000 N/C. If the voltage is doubled and the distance between the plates is reduced to 1/5 the original distance, the magnitude of the new electric field is

(A) 800 N/C
(B) 1,600 N/C
(C) 2,400 N/C
(D) 5,000 N/C
(E) 20,000 N/C

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Questions 15-16 refer to the following diagram that shows part of a closed electrical circuit.



15. The electrical resistance of the part of the circuit shown between point X and point Y is

(A) $1\frac{1}{3}\ \Omega$

(B) $2\ \Omega$

(C) $2\frac{3}{4}\ \Omega$

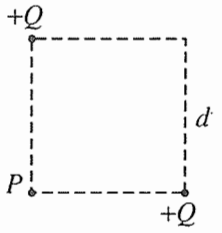
(D) $4\ \Omega$

(E) $6\ \Omega$

16. When there is a steady current in the circuit, the amount of charge passing a point per unit of time is

(A) the same everywhere in the circuit
(B) greater at point X than at point Y
(C) greater in the 1 Ω resistor than in the 2 Ω resistor
(D) greater in the 1 Ω resistor than in the 3 Ω resistor
(E) greater in the 2 Ω resistor than in the 3 Ω resistor

Questions 17-18



The figure above shows two particles, each with a charge of $+Q$, that are located at the opposite corners of a square of side d.

17. What is the direction of the net electric field at point P?

(A) ↖
(B) ↗
(C) ↙
(D) ↘
(E) ↓

18. What is the potential energy of a particle of charge $+q$ that is held at point P?

(A) Zero

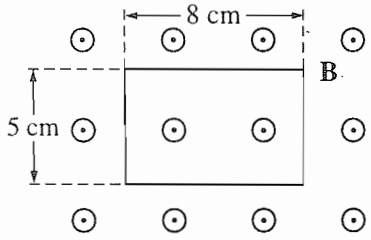
(B) $\frac{\sqrt{2}}{4\pi\epsilon_0}\frac{qQ}{d}$

(C) $\frac{1}{4\pi\epsilon_0}\frac{qQ}{d}$

(D) $\frac{2}{4\pi\epsilon_0}\frac{qQ}{d}$

(E) $\frac{2\sqrt{2}}{4\pi\epsilon_0}\frac{qQ}{d}$

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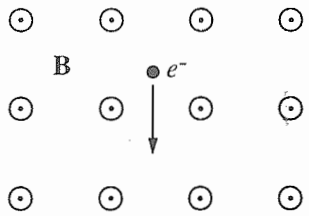


19. A rectangular wire loop is at rest in a uniform magnetic field **B** of magnitude 2 T that is directed out of the page. The loop measures 5 cm by 8 cm, and the plane of the loop is perpendicular to the field, as shown above. The total magnetic flux through the loop is

(A) zero
(B) 2×10^{-3} T·m^2
(C) 8×10^{-3} T·m^2
(D) 2×10^{-1} T·m^2
(E) 8×10^{-1} T·m^2

20. A certain coffeepot draws 4.0 A of current when it is operated on 120 V household lines. If electrical energy costs 10 cents per kilowatt-hour, how much does it cost to operate the coffeepot for 2 hours?

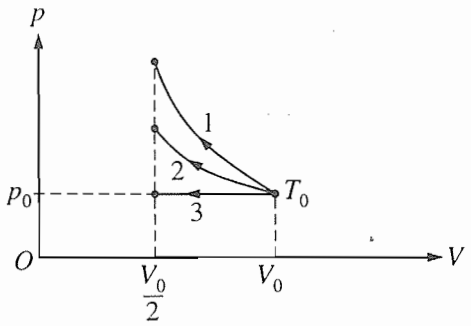
(A) 2.4 cents
(B) 4.8 cents
(C) 8.0 cents
(D) 9.6 cents
(E) 16 cents



21. An electron is in a uniform magnetic field **B** that is directed out of the plane of the page, as shown above. When the electron is moving in the plane of the page in the direction indicated by the arrow, the force on the electron is directed

(A) toward the right
(B) out of the page
(C) into the page
(D) toward the top of the page
(E) toward the bottom of the page

Questions 22-23



A certain quantity of an ideal gas initially at temperature T_0, pressure p_0, and volume V_0 is compressed to one-half its initial volume. As shown above, the process may be adiabatic (process 1), isothermal (process 2), or isobaric (process 3).

22. Which of the following is true of the mechanical work done on the gas?

(A) It is greatest for process 1.
(B) It is greatest for process 3.
(C) It is the same for processes 1 and 2 and less for process 3.
(D) It is the same for processes 2 and 3 and less for process 1.
(E) It is the same for all three processes.

23. Which of the following is true of the final temperature of this gas?

(A) It is greatest for process 1.
(B) It is greatest for process 2.
(C) It is greatest for process 3.
(D) It is the same for processes 1 and 2.
(E) It is the same for processes 1 and 3.

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24. In a certain process, 400 J of heat is added to a system and the system simultaneously does 100 J of work. The change in internal energy of the system is

(A) 500 J
(B) 400 J
(C) 300 J
(D) −100 J
(E) −300 J

25. An ice cube of mass m and specific heat c_i is initially at temperature T_1, where $T_1 < 273$ K. If L is the latent heat of fusion of water, and the specific heat of water is c_w, how much energy is required to convert the ice cube to water at temperature T_2, where $273 \text{ K} < T_2 < 373 \text{ K}$?

(A) $m[c_i(273 - T_1) + L + c_w(373 - T_2)]$

(B) $m[c_i(273 - T_1) + L + c_w(T_2 - 273)]$

(C) $c_i(273 - T_1) + c_w(T_2 - 273)$

(D) $mL + c_w(T_2 - T_1)$

(E) $mL + \left(\frac{c_w + c_i}{2}\right)(T_2 - T_1)$

26. A concave mirror with a radius of curvature of 1.0 m is used to collect light from a distant star. The distance between the mirror and the image of the star is most nearly

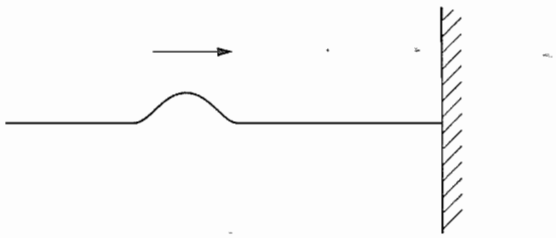
(A) 0.25 m
(B) 0.50 m
(C) 0.75 m
(D) 1.0 m
(E) 2.0 m

27. When light passes from air into water, the frequency of the light remains the same. What happens to the speed and the wavelength of light as it crosses the boundary in going from air into water?

	Speed	Wavelength
(A)	Increases	Remains the same
(B)	Remains the same	Decreases
(C)	Remains the same	Remains the same
(D)	Decreases	Increases
(E)	Decreases	Decreases

28. A physics student places an object 6.0 cm from a converging lens of focal length 9.0 cm. What is the magnitude of the magnification of the image produced?

(A) 0.6
(B) 1.5
(C) 2.0
(D) 3.0
(E) 3.6

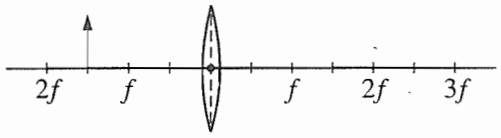


29. One end of a horizontal string is fixed to a wall. A transverse wave pulse is generated at the other end, moves toward the wall as shown above, and is reflected at the wall. Properties of the reflected pulse include which of the following?

I. It has a greater speed than that of the incident pulse.
II. It has a greater amplitude than that of the incident pulse.
III. It is on the opposite side of the string from the incident pulse.

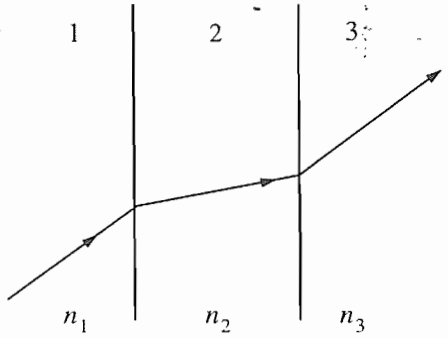
(A) I only
(B) III only
(C) I and II only
(D) II and III only
(E) I, II, and III

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30. An object is placed at a distance of $1.5f$ from a converging lens of focal length f, as shown above. What type of image is formed and what is its size relative to the object?

	Type	Size
(A)	Virtual	Larger
(B)	Virtual	Same size
(C)	Virtual	Smaller
(D)	Real	Larger
(E)	Real	Smaller



31. A light ray passes through substances 1, 2, and 3, as shown above. The indices of refraction for these three substances are n_1, n_2, and n_3, respectively. Ray segments in 1 and in 3 are parallel. From the directions of the ray, one can conclude that

(A) n_3 must be the same as n_1
(B) n_2 must be less than n_1
(C) n_2 must be less than n_3
(D) n_1 must be equal to 1.00
(E) all three indices must be the same

32. At noon a radioactive sample decays at a rate of 4,000 counts per minute. At 12:30 P.M. the decay rate has decreased to 2,000 counts per minute. The predicted decay rate at 1:30 P.M. is

(A) 0 counts per minute
(B) 500 counts per minute
(C) 667 counts per minute
(D) 1,000 counts per minute
(E) 1,333 counts per minute

33. A negative beta particle and a gamma ray are emitted during the radioactive decay of a nucleus of $^{214}_{82}\text{Pb}$. Which of the following is the resulting nucleus?

(A) $^{210}_{80}\text{Hg}$

(B) $^{214}_{81}\text{Tl}$

(C) $^{213}_{83}\text{Bi}$

(D) $^{214}_{83}\text{Bi}$

(E) $^{218}_{84}\text{Po}$

34. If the momentum of an electron doubles, its de Broglie wavelength is multiplied by a factor of

(A) $\frac{1}{4}$

(B) $\frac{1}{2}$

(C) 1

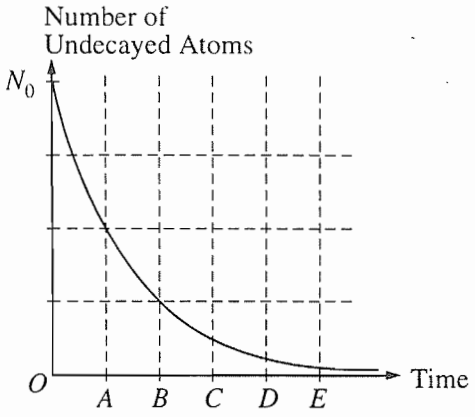
(D) 2

(E) 4

35. Quantum concepts are critical in explaining all of the following EXCEPT

(A) Rutherford's scattering experiments
(B) Bohr's theory of the hydrogen atom
(C) Compton scattering
(D) the blackbody spectrum
(E) the photoelectric effect

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36. The graph above shows the decay of a sample of carbon 14 that initially contained N_0 atoms. Which of the lettered points on the time axis could represent the half-life of carbon 14 ?

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

37. If photons of light of frequency f have momentum p, photons of light of frequency $2f$ will have a momentum of

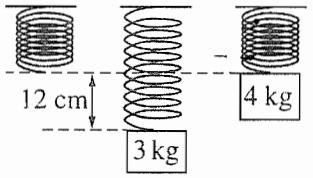
(A) $2p$

(B) $\sqrt{2}\,p$

(C) p

(D) $\frac{p}{\sqrt{2}}$

(E) $\frac{1}{2}p$



38. A block of mass 3.0 kg is hung from a spring, causing it to stretch 12 cm at equilibrium, as shown above. The 3.0 kg block is then replaced by a 4.0 kg block, and the new block is released from the position shown above, at which the spring is unstretched. How far will the 4.0 kg block fall before its direction is reversed?

(A) 9 cm
(B) 18 cm
(C) 24 cm
(D) 32 cm
(E) 48 cm

39. An object has a weight W when it is on the surface of a planet of radius R. What will be the gravitational force on the object after it has been moved to a distance of $4R$ from the center of the planet?

(A) $16W$

(B) $4W$

(C) W

(D) $\frac{1}{4}W$

(E) $\frac{1}{16}W$

40. What is the kinetic energy of a satellite of mass m that orbits the Earth, of mass M, in a circular orbit of radius R ?

(A) Zero

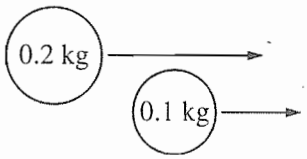
(B) $\frac{1}{2}\frac{GMm}{R}$

(C) $\frac{1}{4}\frac{GMm}{R}$

(D) $\frac{1}{2}\frac{GMm}{R^2}$

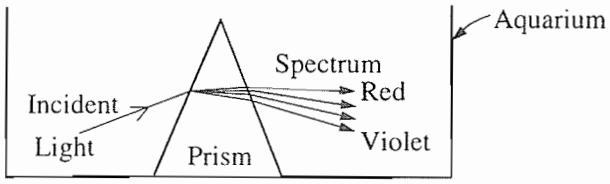
(E) $\frac{GMm}{R^2}$

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41. Two objects of mass 0.2 kg and 0.1 kg, respectively, move parallel to the x-axis, as shown above. The 0.2 kg object overtakes and collides with the 0.1 kg object. Immediately after the collision, the y-component of the velocity of the 0.2 kg object is 1 m/s upward. What is the y-component of the velocity of the 0.1 kg object immediately after the collision?

(A) 2 m/s downward
(B) 0.5 m/s downward
(C) 0 m/s
(D) 0.5 m/s upward
(E) 2 m/s upward

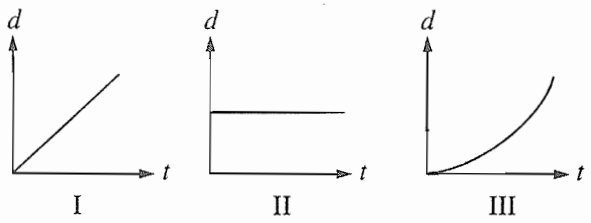


42. A beam of white light is incident on a triangular glass prism with an index of refraction of about 1.5 for visible light, producing a spectrum. Initially, the prism is in a glass aquarium filled with air, as shown above. If the aquarium is filled with water with an index of refraction of 1.3, which of the following is true?

(A) No spectrum is produced.
(B) A spectrum is produced, but the deviation of the beam is opposite to that in air.
(C) The positions of red and violet are reversed in the spectrum.
(D) The spectrum produced has greater separation between red and violet than that produced in air.
(E) The spectrum produced has less separation between red and violet than that produced in air.

Questions 43-44

Three objects can only move along a straight, level path. The graphs below show the position d of each of the objects plotted as a function of time t.



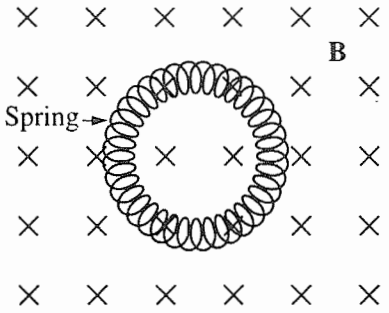
43. The magnitude of the momentum of the object is increasing in which of the cases?

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

44. The sum of the forces on the object is zero in which of the cases?

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

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45. A metal spring has its ends attached so that it forms a circle. It is placed in a uniform magnetic field, as shown above. Which of the following will NOT cause a current to be induced in the spring?

(A) Changing the magnitude of the magnetic field
(B) Increasing the diameter of the circle by stretching the spring
(C) Rotating the spring about a diameter
(D) Moving the spring parallel to the magnetic field
(E) Moving the spring in and out of the magnetic field

Questions 46-47

A magnetic field of 0.1 T forces a proton beam of 1.5 mA to move in a circle of radius 0.1 m. The plane of the circle is perpendicular to the magnetic field.

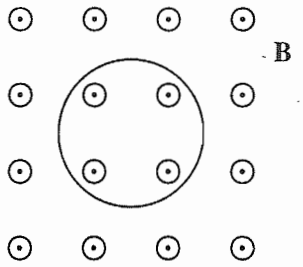
46. Of the following, which is the best estimate of the work done by the magnetic field on the protons during one complete orbit of the circle?

(A) 0 J
(B) 10^{-22} J
(C) 10^{-5} J
(D) 10^{2} J
(E) 10^{20} J

47. Of the following, which is the best estimate of the speed of a proton in the beam as it moves in the circle?

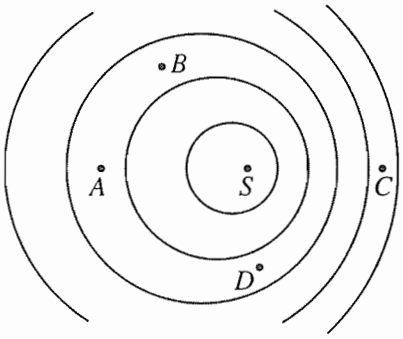
(A) 10^{-2} m/s
(B) 10^{3} m/s
(C) 10^{6} m/s
(D) 10^{8} m/s
(E) 10^{15} m/s

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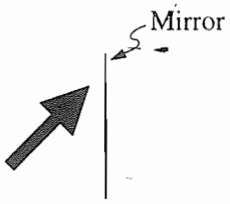
48. A single circular loop of wire in the plane of the page is perpendicular to a uniform magnetic field **B** directed out of the page, as shown above. If the magnitude of the magnetic field is decreasing, then the induced current in the wire is

(A) directed upward out of the paper
(B) directed downward into the paper
(C) clockwise around the loop
(D) counterclockwise around the loop
(E) zero (no current is induced)



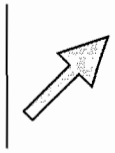
49. A small vibrating object on the surface of a ripple tank is the source of waves of frequency 20 Hz and speed 60 cm/s. If the source S is moving to the right, as shown above, with speed 20 cm/s, at which of the labeled points will the frequency measured by a stationary observer be greatest?

(A) *A*
(B) *B*
(C) *C*
(D) *D*
(E) It will be the same at all four points.

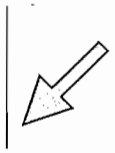


50. An object, slanted at an angle of 45°, is placed in front of a vertical plane mirror, as shown above. Which of the following shows the apparent position and orientation of the object's image?

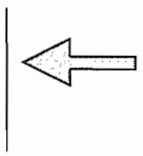
(A)



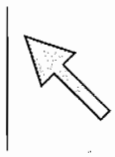
(B)



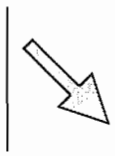
(C)



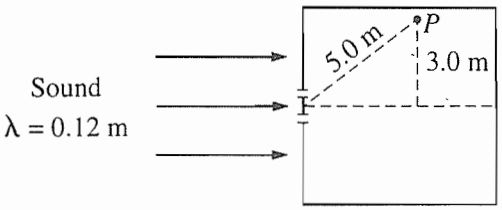
(D)



(E)

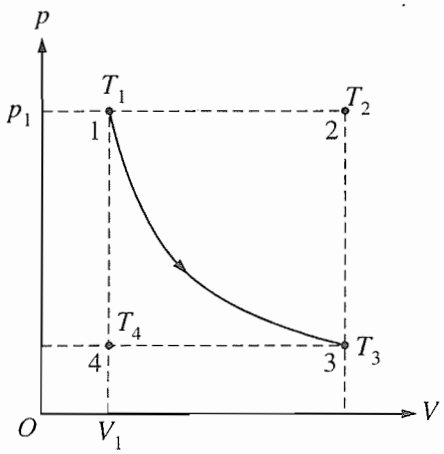


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51. Plane sound waves of wavelength 0.12 m are incident on two narrow slits in a box with nonreflecting walls, as shown above. At a distance of 5.0 m from the center of the slits, a first-order maximum occurs at point P, which is 3.0 m from the central maximum. The distance between the slits is most nearly

(A) 0.07 m
(B) 0.09 m
(C) 0.16 m
(D) 0.20 m
(E) 0.24 m



52. An ideal gas is initially in a state that corresponds to point 1 on the graph above, where it has pressure p_1, volume V_1, and temperature T_1. The gas undergoes an isothermal process represented by the curve shown, which takes it to a final state 3 at temperature T_3. If T_2 and T_4 are the temperatures the gas would have at points 2 and 4, respectively, which of the following relationships is true?

(A) $T_1 < T_3$
(B) $T_1 < T_2$
(C) $T_1 < T_4$
(D) $T_1 = T_2$
(E) $T_1 = T_4$

53. The absolute temperature of a sample of monatomic ideal gas is doubled at constant volume. What effect, if any, does this have on the pressure and density of the sample of gas?

	Pressure	Density
(A)	Remains the same	Remains the same
(B)	Remains the same	Doubles
(C)	Doubles	Remains the same
(D)	Doubles	Is multiplied by a factor of 4
(E)	Is multiplied by a factor of 4	Doubles

54. The disk-shaped head of a pin is 1.0 mm in diameter. Which of the following is the best estimate of the number of atoms in the layer of atoms on the top surface of the pinhead?

(A) 10^4
(B) 10^{14}
(C) 10^{24}
(D) 10^{34}
(E) 10^{50}

55. 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.

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56. An object moves up and down the y-axis with an acceleration given as a function of time t by the expression $a = A \sin \omega t$, where A and ω are constants. What is the period of this motion?

(A) ω

(B) $2\pi\omega$

(C) $\omega^2 A$

(D) $\frac{2\pi}{\omega}$

(E) $\frac{\omega}{2\pi}$

57. A ball of mass 0.4 kg is initially at rest on the ground. It is kicked and leaves the kicker's foot with a speed of 5.0 m/s in a direction 60° above the horizontal. The magnitude of the impulse imparted by the ball to the foot is most nearly

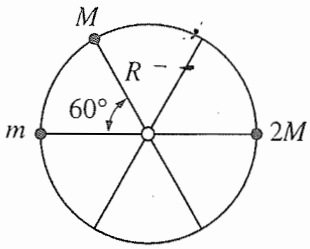
(A) 1 N·s

(B) $\sqrt{3}$ N·s

(C) 2 N·s

(D) $\frac{2}{\sqrt{3}}$ N·s

(E) 4 N·s



58. A wheel of radius R and negligible mass is mounted on a horizontal frictionless axle so that the wheel is in a vertical plane. Three small objects having masses m, M, and $2M$, respectively, are mounted on the rim of the wheel, as shown above. If the system is in static equilibrium, what is the value of m in terms of M ?

(A) $\frac{M}{2}$

(B) M

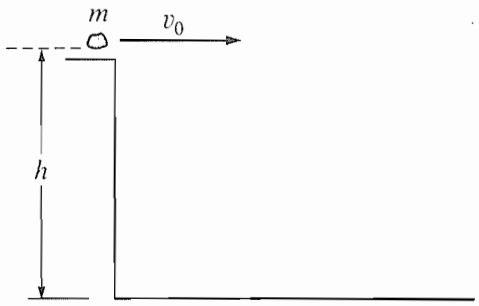
(C) $\frac{3M}{2}$

(D) $2M$

(E) $\frac{5M}{2}$

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Questions 59-60



A rock of mass m is thrown horizontally off a building from a height h, as shown above. The speed of the rock as it leaves the thrower's hand at the edge of the building is v_0.

59. How much time does it take the rock to travel from the edge of the building to the ground?

(A) $\sqrt{hv_0}$
(B) h/v_0
(C) hv_0/g
(D) $2h/g$
(E) $\sqrt{2h/g}$

60. What is the kinetic energy of the rock just before it hits the ground?

(A) mgh
(B) $\frac{1}{2}mv_0^2$
(C) $\frac{1}{2}mv_0^2 - mgh$
(D) $\frac{1}{2}mv_0^2 + mgh$
(E) $mgh - \frac{1}{2}mv_0^2$

61. Which of the following statements is NOT a correct assumption of the classical model of an ideal gas?

(A) The molecules are in random motion.
(B) The volume of the molecules is negligible compared with the volume occupied by the gas.
(C) The molecules obey Newton's laws of motion.
(D) The collisions between molecules are inelastic.
(E) The only appreciable forces on the molecules are those that occur during collisions.

62. A sample of an ideal gas is in a tank of constant volume. The sample absorbs heat energy so that its temperature changes from 300 K to 600 K. If v_1 is the average speed of the gas molecules before the absorption of heat and v_2 is their average speed after the absorption of heat, what is the ratio v_2/v_1 ?

(A) $\frac{1}{2}$
(B) 1
(C) $\sqrt{2}$
(D) 2
(E) 4

63. Two people of unequal mass are initially standing still on ice with negligible friction. They then simultaneously push each other horizontally. Afterward, which of the following is true?

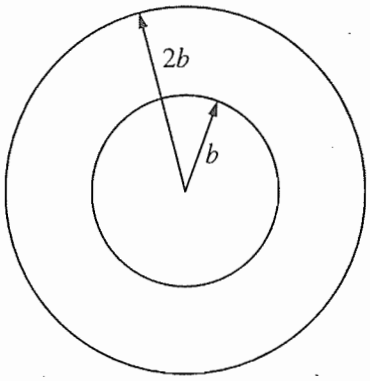
(A) The kinetic energies of the two people are equal.
(B) The speeds of the two people are equal.
(C) The momenta of the two people are of equal magnitude.
(D) The center of mass of the two-person system moves in the direction of the less massive person.
(E) The less massive person has a smaller initial acceleration than the more massive person.

64. Two parallel conducting plates, separated by a distance d, are connected to a battery of emf $\mathcal{E}$. Which of the following is correct if the plate separation is doubled while the battery remains connected?

(A) The electric charge on the plates is doubled.
(B) The electric charge on the plates is halved.
(C) The potential difference between the plates is doubled.
(D) The potential difference between the plates is halved.
(E) The capacitance is unchanged.

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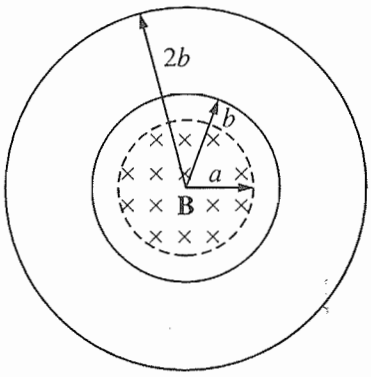
Questions 65-66



Two concentric circular loops of radii b and $2b$, made of the same type of wire, lie in the plane of the page, as shown above.

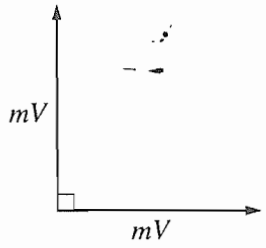
65. The total resistance of the wire loop of radius b is R. What is the resistance of the wire loop of radius $2b$?

(A) $R/4$
(B) $R/2$
(C) R
(D) $2R$
(E) $4R$



66. A uniform magnetic field **B** that is perpendicular to the plane of the page now passes through the loops, as shown above. The field is confined to a region of radius a, where $a < b$, and is changing at a constant rate. The induced emf in the wire loop of radius b is $\mathcal{E}$. What is the induced emf in the wire loop of radius $2b$?

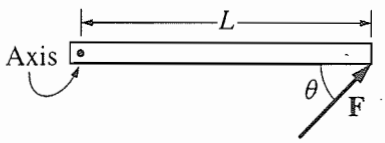
(A) Zero
(B) $\mathcal{E}/2$
(C) $\mathcal{E}$
(D) $2\mathcal{E}$
(E) $4\mathcal{E}$



67. A stationary object explodes, breaking into three pieces of masses m, m, and $3m$. The two pieces of mass m move off at right angles to each other with the same magnitude of momentum mV, as shown in the diagram above. What are the magnitude and direction of the velocity of the piece having mass $3m$?

	Magnitude	Direction
(A)	$\frac{V}{\sqrt{3}}$	↗
(B)	$\frac{V}{\sqrt{3}}$	↙
(C)	$\frac{\sqrt{2}\,V}{3}$	↗
(D)	$\frac{\sqrt{2}\,V}{3}$	↙
(E)	$\sqrt{2}\,V$	↙

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View from Above

68. A rod on a horizontal tabletop is pivoted at one end and is free to rotate without friction about a vertical axis, as shown above. A force **F** is applied at the other end, at an angle θ to the rod. If **F** were to be applied perpendicular to the rod, at what distance from the axis should it be applied in order to produce the same torque?

(A) $L \sin \theta$
(B) $L \cos \theta$
(C) L
(D) $L \tan \theta$
(E) $\sqrt{2}\, L$

69. Which of the following imposes a limit on the number of electrons in an energy state of an atom?

(A) The Heisenberg uncertainty principle
(B) The Pauli exclusion principle
(C) The Bohr model of the hydrogen atom
(D) The theory of relativity
(E) The law of conservation of energy

70. A 4 μF capacitor is charged to a potential difference of 100 V. The electrical energy stored in the capacitor is

(A) 2×10^{-10} J
(B) 2×10^{-8} J
(C) 2×10^{-6} J
(D) 2×10^{-4} J
(E) 2×10^{-2} J

STOP

END OF SECTION I

IF YOU FINISH BEFORE TIME IS CALLED, YOU MAY CHECK YOUR WORK ON THIS SECTION.

DO NOT GO ON TO SECTION II UNTIL YOU ARE TOLD TO DO SO.