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

College Board Regional Offices

National Office: Wade Curry/Philip Arbolino/Charlotte Gill/Frederick Wright
45 Columbus Avenue, New York, NY 10023-6992
(212) 713-8000
E-mail: wcurry@collegeboard.org, parbolino@collegeboard.org, cgill@collegeboard.org, fwright@collegeboard.org

Middle States: Mary Alice McCullough/Michael Marsh
Suite 410, 3440 Market Street, Philadelphia, PA 19104-3338
(215) 387-7600
E-mail: mmccullough@collegeboard.org, mmarsh@collegeboard.org

(Serving Delaware, District of Columbia, Maryland, New Jersey, New York, Pennsylvania, and Puerto Rico)

Midwestern: Bob McDonough/Paula Herron/Ann Winship
Suite 1001, 1560 Sherman Avenue, Evanston, IL 60201-4805
(847) 866-1700
E-mail: rmcdonough@collegeboard.org, pherron@collegeboard.org, awinship@collegeboard.org

(Serving Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, West Virginia, and Wisconsin)

New England: Fred Wetzel
470 Totten Pond Road, Waltham, MA 02451-1982
(781) 890-9150
E-mail: fwetzel@collegeboard.org

(Serving Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont)

Southern: Geoffrey Freer/Tom New
Suite 340, 100 Crescent Centre Parkway, Tucker, GA 30084-7039
(770) 908-9737
E-mail: gfreer@collegeboard.org, tnew@collegeboard.org

(Serving Alabama, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia)

Southwestern: Frances Brown/Scott Kampmeier/Joe Milliet/Mondy Raibon
Suite 1050, 98 San Jacinto Boulevard, Austin, TX 78701-4039
(512) 472-0231
E-mail: fbrown@collegeboard.org, skampmeier@collegeboard.org, jmilliet@collegeboard.org, mraibon@collegeboard.org

(Serving Arkansas, New Mexico, Oklahoma, and Texas)

Dallas/Ft. Worth Metroplex AP Office: Kay Wilson
P.O. Box 19666, Room 108, 600 South West Street, Arlington, TX 76019
(817) 272-7200
E-mail: kwilson@collegeboard.org

Western: Claire Pelton/Gail Chapman
Suite 480, 2099 Gateway Place, San Jose, CA 95110-1017
(408) 452-1400
E-mail: cpelton@collegeboard.org, gchapman@collegeboard.org

(Serving Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, Oregon, Utah, Washington, and Wyoming)

AP Consultant in Canada: George Ewonus
212-1755 Springfield Road
Kelowna, B.C., Canada V1Y 5V5
(250) 861-9050; (800) 667-4548 in Canada only
E-mail: gewonus@ap.ca

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

Contains:

Chapter I The AP Process

- Who Develops the AP Physics Exams?
- How Do They Develop Them?
  - Section I
  - Section II
- Question Types
  - Multiple Choice
  - Free Response
- Scoring the Exams
  - Who Scores the AP Physics Exams?
  - Ensuring Accuracy
  - How the Scoring Guidelines are Created
  - Training Faculty Consultants to Apply the Scoring Guidelines
- Maintaining the Scoring Guidelines
- 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."

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

(A) ● (C) (D) (E)

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.

TABLE OF INFORMATION FOR 1998

CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1 u = 1.66 \times 10^{-27}$ kg
	$= 931 \text{ MeV}/c^2$
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,	$N_0 = 6.02 \times 10^{23} \text{ mol}^{-1}$
Universal gas constant,	$R = 8.31 \text{ J}/(\text{mol} \cdot \text{K})$
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,	$h = 6.63 \times 10^{-34} \text{ J} \cdot \text{s}$
	$= 4.14 \times 10^{-15} \text{ eV} \cdot \text{s}$
	$hc = 1.99 \times 10^{-25} \text{ J} \cdot \text{m}$
	$= 1.24 \times 10^3 \text{ eV} \cdot \text{nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7} (\text{T} \cdot \text{m})/\text{A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7} (\text{T} \cdot \text{m})/\text{A}$
Universal gravitational constant,	$G = 6.67 \times 10^{-11} \text{ m}^3/\text{kg} \cdot \text{s}^2$
Acceleration due to gravity at the Earth's surface,	$g = 9.8 \text{ m/s}^2$
1 atmosphere pressure,	$1 \text{ atm} = 1.0 \times 10^5 \text{ N/m}^2$
	$= 1.0 \times 10^5$ Pa
1 electron volt,	$1 \text{ eV} = 1.60 \times 10^{-19}$ J
1 angstrom,	$1 \text{Å} = 1 \times 10^{-10}$ 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?

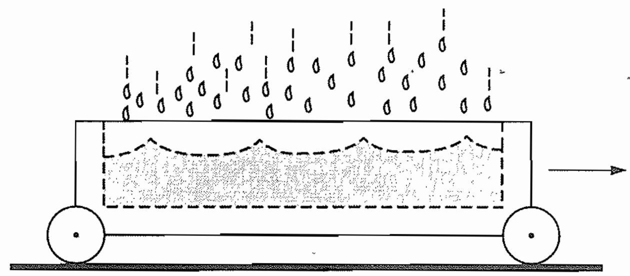
(A) $\frac{v}{2}$

(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

GO ON TO THE NEXT PAGE

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) $9\,\dfrac{\text{N}\cdot\text{m}}{\text{kg}}$

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

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

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

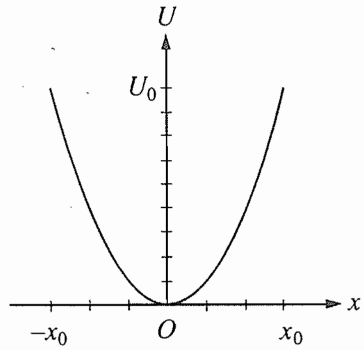
(E) $24\,\dfrac{\text{kg}\cdot\text{m}^2}{\text{s}}$

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.

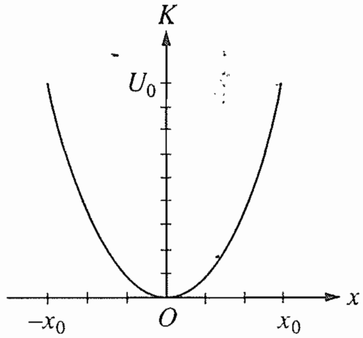
(A) I only
(B) II only
(C) I and III only
(D) II and III only
(E) I, II, and III

GO ON TO THE NEXT PAGE

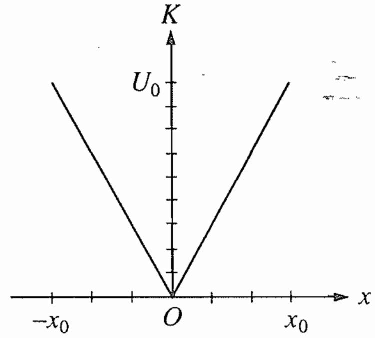


8. The graph above represents the potential energy U as a function of displacement x for an object on the end of a spring oscillating in simple harmonic motion with amplitude x_0. Which of the following graphs represents the kinetic energy K of the object as a function of displacement x ?

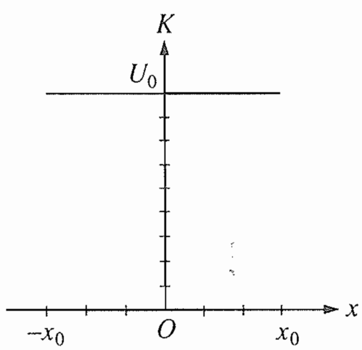
(A)



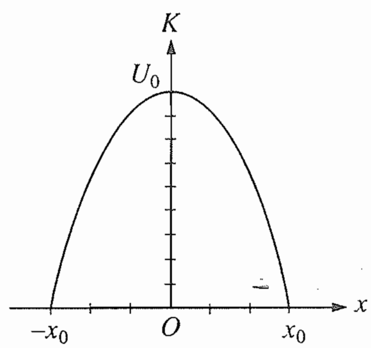
(B)



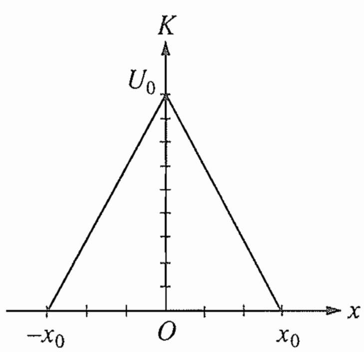
(C)



(D)



(E)



GO ON TO THE NEXT PAGE

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?

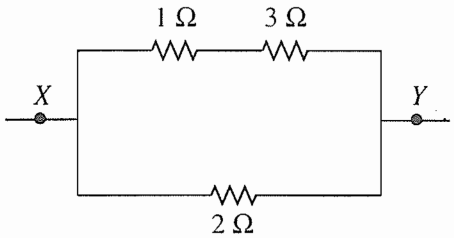
(A) It is zero.
(B) It is in the direction of the field.
(C) It is in the direction opposite to the field.
(D) It produces a torque on the sphere about the direction of the field.
(E) It causes the sphere to oscillate about an equilibrium position.

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

GO ON TO THE NEXT PAGE

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

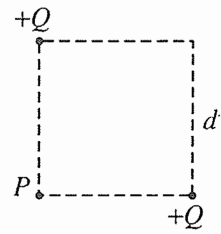
(D) $4\ \Omega$

(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

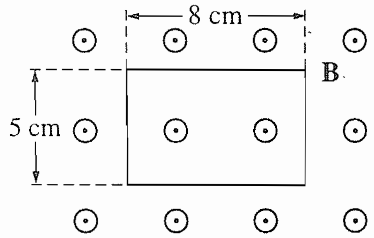
(B) $\frac{\sqrt{2}}{4\pi\epsilon_0}\frac{qQ}{d}$

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

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

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

GO ON TO THE NEXT PAGE

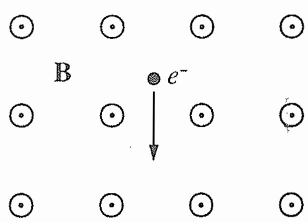


19. A rectangular wire loop is at rest in a uniform magnetic field **B** of magnitude 2 T that is directed out of the page. The loop measures 5 cm by 8 cm, and the plane of the loop is perpendicular to the field, as shown above. The total magnetic flux through the loop is

(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?

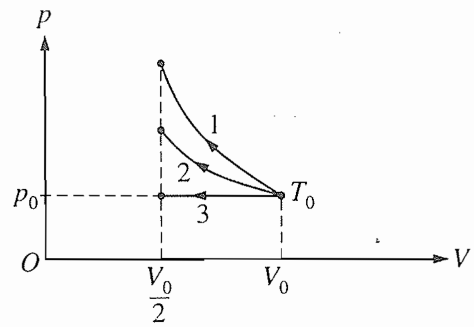
(A) 2.4 cents
(B) 4.8 cents
(C) 8.0 cents
(D) 9.6 cents
(E) 16 cents



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.

GO ON TO THE NEXT PAGE

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 $273\text{ K} < T_2 < 373$ 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

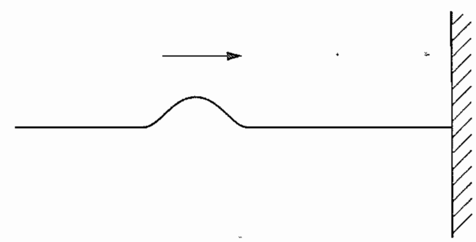
(A) 0.25 m
(B) 0.50 m
(C) 0.75 m
(D) 1.0 m
(E) 2.0 m

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

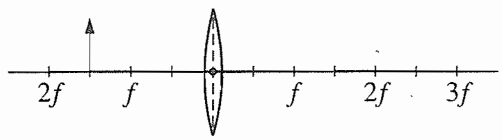


29. One end of a horizontal string is fixed to a wall. A transverse wave pulse is generated at the other end, moves toward the wall as shown above, and is reflected at the wall. Properties of the reflected pulse include which of the following?

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.

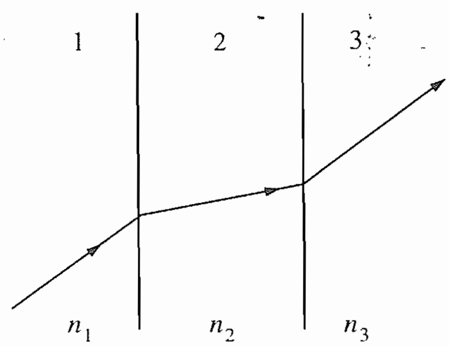
(A) I only
(B) III only
(C) I and II only
(D) II and III only
(E) I, II, and III

GO ON TO THE NEXT PAGE



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

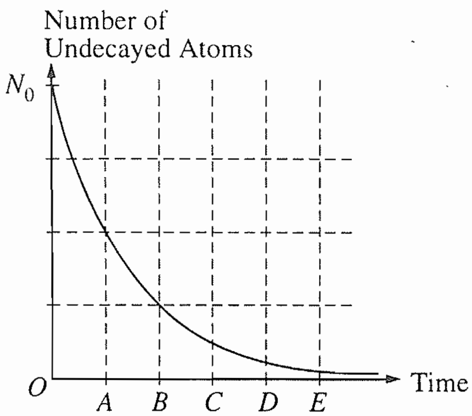
(D) 2

(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

GO ON TO THE NEXT PAGE



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

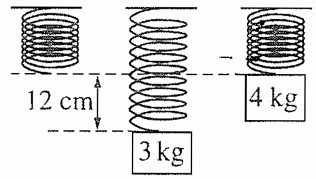
(A) $2p$

(B) $\sqrt{2}p$

(C) p

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

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



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) $\dfrac{1}{4}W$

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

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

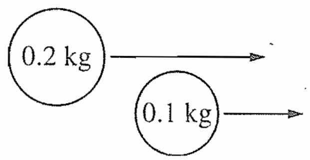
(B) $\dfrac{1}{2}\dfrac{GMm}{R}$

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

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

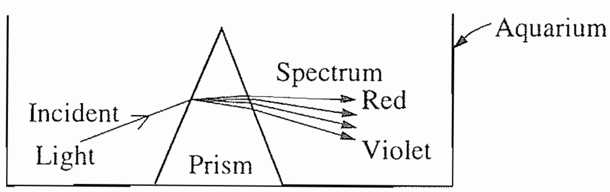
(E) $\dfrac{GMm}{R^2}$

GO ON TO THE NEXT PAGE



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

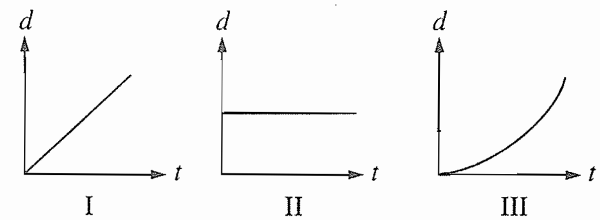


42. A beam of white light is incident on a triangular glass prism with an index of refraction of about 1.5 for visible light, producing a spectrum. Initially, the prism is in a glass aquarium filled with air, as shown above. If the aquarium is filled with water with an index of refraction of 1.3, which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



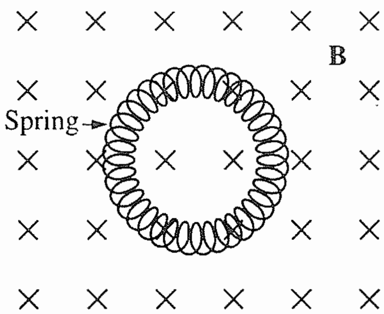
43. The magnitude of the momentum of the object is increasing in which of the cases?

(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

GO ON TO THE NEXT PAGE



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

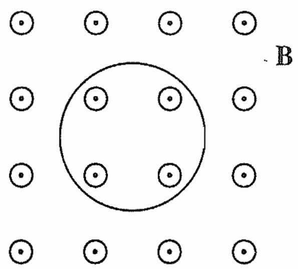
A magnetic field of 0.1 T forces a proton beam of 1.5 mA to move in a circle of radius 0.1 m. The plane of the circle is perpendicular to the magnetic field.

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

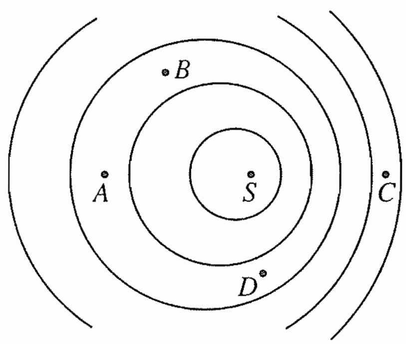
47. Of the following, which is the best estimate of the speed of a proton in the beam as it moves in the circle?

(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



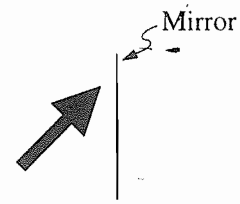
48. A single circular loop of wire in the plane of the page is perpendicular to a uniform magnetic field **B** directed out of the page, as shown above. If the magnitude of the magnetic field is decreasing, then the induced current in the wire is

(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)



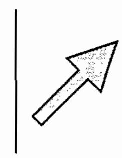
49. A small vibrating object on the surface of a ripple tank is the source of waves of frequency 20 Hz and speed 60 cm/s. If the source S is moving to the right, as shown above, with speed 20 cm/s, at which of the labeled points will the frequency measured by a stationary observer be greatest?

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

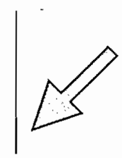


50. An object, slanted at an angle of 45°, is placed in front of a vertical plane mirror, as shown above. Which of the following shows the apparent position and orientation of the object's image?

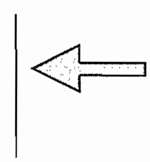
(A)



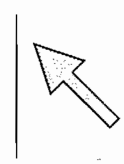
(B)



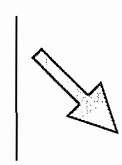
(C)

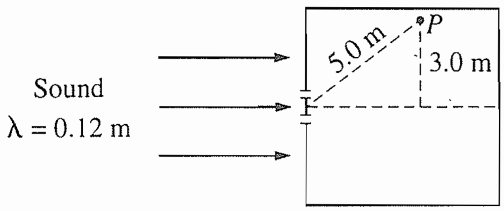


(D)



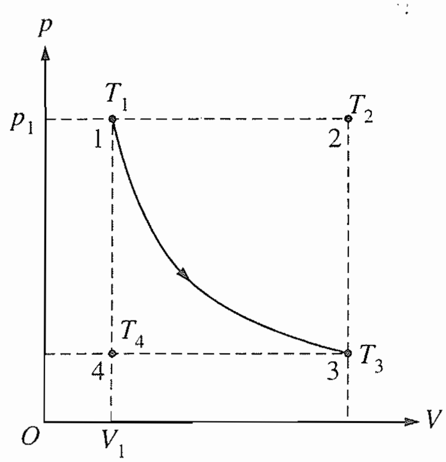
(E)





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.

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) $\dfrac{2\pi}{\omega}$

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

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

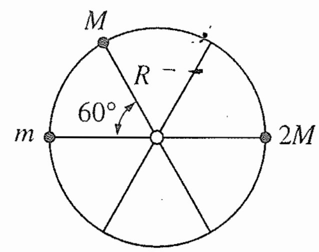
(A) 1 N·s

(B) $\sqrt{3}$ N·s

(C) 2 N·s

(D) $\dfrac{2}{\sqrt{3}}$ 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) $\dfrac{M}{2}$

(B) M

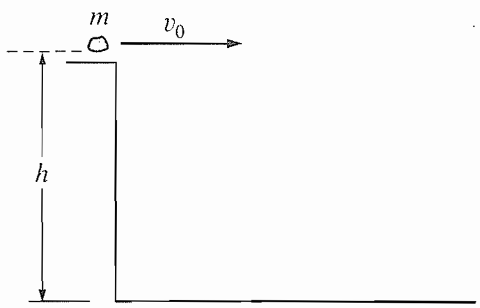
(C) $\dfrac{3M}{2}$

(D) $2M$

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

GO ON TO THE NEXT PAGE

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?

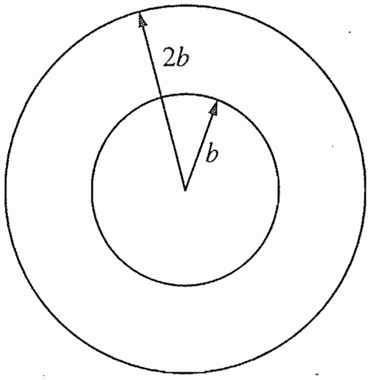
(A) The kinetic energies of the two people are equal.
(B) The speeds of the two people are equal.
(C) The momenta of the two people are of equal magnitude.
(D) The center of mass of the two-person system moves in the direction of the less massive person.
(E) The less massive person has a smaller initial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

GO ON TO THE NEXT PAGE

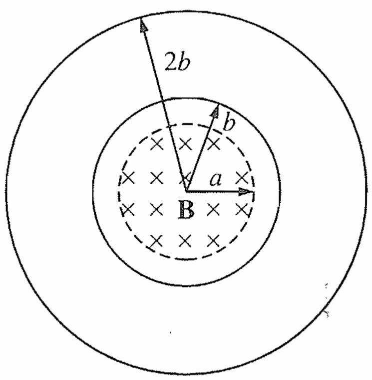
Questions 65-66



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.

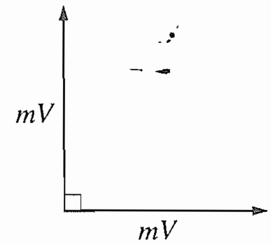
65. The total resistance of the wire loop of radius b is R. What is the resistance of the wire loop of radius $2b$?

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



66. A uniform magnetic field $\mathbf{B}$ 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 $2b$?

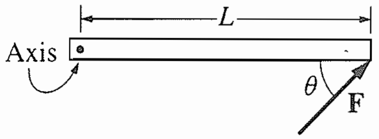
(A) Zero
(B) $\mathcal{E}/2$
(C) $\mathcal{E}$
(D) $2\mathcal{E}$
(E) $4\mathcal{E}$



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)	$\sqrt{2}\,V$	↙

GO ON TO THE NEXT PAGE



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

S T O P

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.

PHYSICS B

SECTION II

Free-Response Questions

Time—90 minutes

Required questions 1-2 on pages 4-7—15 points each

Required questions 3-8 on pages 8-19—10 points each

Percent of total grade—50

General Instructions

When you are told to begin, carefully tear out the green insert, and start work. The questions in the green insert are duplicates of those in this booklet, except that in this booklet space has been left after each part of each question for you to write your answers. The green insert may be used for reference only as you answer the free-response questions. NO CREDIT WILL BE GIVEN FOR ANYTHING WRITTEN IN THE GREEN INSERT.

A table of information and lists of equations that may be helpful are on pages 1-3 of the green insert. Show your work and write your answers to each question in the pink booklet only. Be sure to write CLEARLY and LEGIBLY. Credit for your answers depends on your demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should show your work for each part in the space provided after that part. If you need more space, be sure to clearly indicate where you continue your work. Credit will NOT be awarded for work that is not clearly designated as the solution to a specific part of a question. Credit for your work also depends on the quality of your solutions and explanations, so you should SHOW YOUR WORK. If you make an error, you may save time by crossing it out rather than trying to erase it. Crossed-out work will not be graded. You may lose credit for incorrect work that is not crossed out.

The College Board
Advanced Placement Examination
PHYSICS B
SECTION II

TABLE OF INFORMATION FOR 1998

CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\,u = 1.66 \times 10^{-27}$ kg
	$= 931\ \text{MeV}/c^2$
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,	$N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$
Universal gas constant,	$R = 8.31\ \text{J}/(\text{mol} \cdot \text{K})$
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,	$h = 6.63 \times 10^{-34}\ \text{J} \cdot \text{s}$
	$= 4.14 \times 10^{-15}\ \text{eV} \cdot \text{s}$
	$hc = 1.99 \times 10^{-25}\ \text{J} \cdot \text{m}$
	$= 1.24 \times 10^3\ \text{eV} \cdot \text{nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N} \cdot \text{m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg} \cdot \text{s}^2$
Acceleration due to gravity at the Earth's surface,	$g = 9.8\ \text{m/s}^2$
1 atmosphere pressure,	$1\ \text{atm} = 1.0 \times 10^5\ \text{N/m}^2$
	$= 1.0 \times 10^5$ Pa
1 electron volt,	$1\ \text{eV} = 1.60 \times 10^{-19}$ J
1 angstrom,	$1\ \text{Å} = 1 \times 10^{-10}$ 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.

This insert may be used for reference and/or scratchwork as you answer the free-response questions, but be sure to show all your work and your answers in the pink booklet. No credit will be given for work shown on this green insert.

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 1998

NEWTONIAN MECHANICS

$v = v_0 + at$

$s = s_0 + v_0 t + \frac{1}{2} at^2$

$v^2 = v_0^2 + 2a(s - s_0)$

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

$F_{fric} \leq \mu N$

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

$\tau = rF \sin \theta$

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

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

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

$\Delta U_g = mgh$

$W = \mathbf{F} \cdot \mathbf{s} = Fs \cos \theta$

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

$P = Fv$

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

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

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

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

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

$F_G = -\frac{Gm_1 m_2}{r^2}$

$U_G = -\frac{Gm_1 m_2}{r}$

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

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$

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

$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$

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

$V = \frac{1}{4\pi\epsilon_0} \sum \frac{q}{r}$

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

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

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

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

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

$V = IR$

$P = IV$

$C_p = \sum_i C_i$

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

$R_s = \sum_i R_i$

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

$F_B = qvB \sin \theta$

$F_B = BI\ell \sin \theta$

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

$\phi_m = \mathbf{B} \cdot \mathbf{A} = BA \cos \theta$

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

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

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

ADVANCED PLACEMENT PHYSICS B EQUATIONS FOR 1998

THERMAL PHYSICS

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

$Q = mL$

$Q = mc\Delta T$

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

$pV = nRT$

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

$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_BT}{\mu}}$

$W = p\Delta V$

$Q = nc\Delta T$

$\Delta U = Q - W$

$\Delta U = nc_V \Delta T$

$e = \frac{W}{Q_H} = \frac{Q_H - Q_C}{Q_H}$

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

A = area
c = specific heat or molar specific heat
e = efficiency
F = force
K_{avg} = average molecular kinetic energy
L = heat of transformation
ℓ = length
M = molar mass
m = mass of sample
n = number of moles
p = pressure
Q = heat transferred
T = temperature
U = internal energy
V = volume
v_{rms} = root-mean-square velocity
W = work done by system
α = coefficient of linear expansion
μ = mass of molecule

ATOMIC AND NUCLEAR PHYSICS

$E = hv = pc$

$K_{max} = hv - \phi$

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

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

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

WAVES AND OPTICS

$v = v\lambda$

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

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

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

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

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

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

$d \sin \theta = m\lambda$

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

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

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

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

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

Parallelepiped
$V = \ell wh$

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

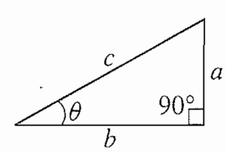
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

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

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

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

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



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

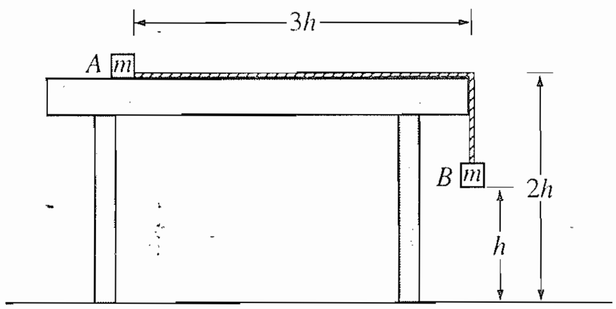
PHYSICS B

SECTION II

Time — 90 minutes

8 Questions

Directions: Answer all eight questions, which are weighted according to the points indicated. The suggested time is about 15 minutes for answering each of questions 1 and 2, which are worth 15 points each, and about 10 minutes for answering each of questions 3-8, which are worth 10 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part, NOT in the green insert.



1. (15 points)
Two small blocks, each of mass m, are connected by a string of constant length $4h$ and negligible mass. Block A is placed on a smooth tabletop as shown above, and block B hangs over the edge of the table. The tabletop is a distance $2h$ above the floor. Block B is then released from rest at a distance h above the floor at time $t = 0$. Express all algebraic answers in terms of h, m, and g.

(a) Determine the acceleration of block B as it descends.

(b) Block B strikes the floor and does not bounce. Determine the time t_1 at which block B strikes the floor.

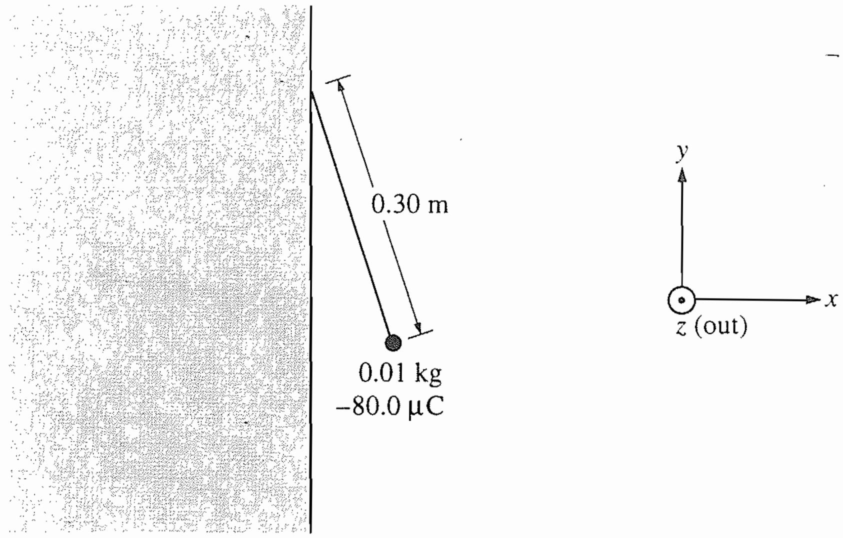
GO ON TO THE NEXT PAGE

(c) Describe the motion of block A from time $t = 0$ to the time when block B strikes the floor.

(d) Describe the motion of block A from the time block B strikes the floor to the time block A leaves the table.

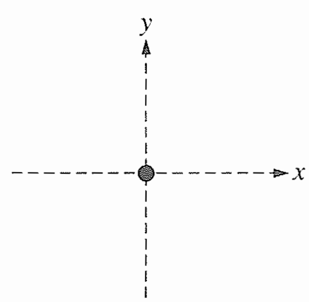
(e) Determine the distance between the landing points of the two blocks.

GO ON TO THE NEXT PAGE



2. (15 points)
A wall has a negative charge distribution producing a uniform horizontal electric field. A small plastic ball of mass 0.01 kg, carrying a charge of −80.0 μC, is suspended by an uncharged, nonconducting thread 0.30 m long. The thread is attached to the wall and the ball hangs in equilibrium, as shown above, in the electric and gravitational fields. The electric force on the ball has a magnitude of 0.032 N.

(a) On the diagram below, draw and label the forces acting on the ball.



(b) Calculate the magnitude of the electric field at the ball's location due to the charged wall, and state its direction relative to the coordinate axes shown.

GO ON TO THE NEXT PAGE

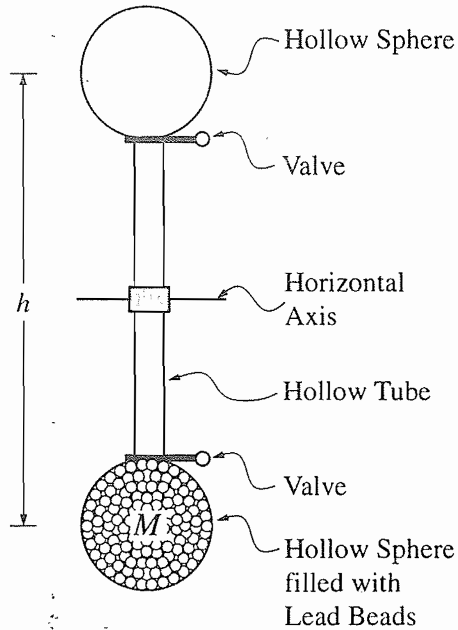
(c) Determine the perpendicular distance from the wall to the center of the ball.

(d) The string is now cut.

i. Calculate the magnitude of the resulting acceleration of the ball, and state its direction relative to the coordinate axes shown.

ii. Describe the resulting path of the ball.

GO ON TO THE NEXT PAGE



3. (10 points)
Students are designing an experiment to demonstrate the conversion of mechanical energy into thermal energy. They have designed the apparatus shown in the figure above. Small lead beads of total mass M and specific heat c fill the lower hollow sphere. The valves between the spheres and the hollow tube can be opened or closed to control the flow of the lead beads. Initially both valves are open.

(a) The lower valve is closed and a student turns the apparatus 180° about a horizontal axis, so that the filled sphere is now on top. This elevates the center of mass of the lead beads by a vertical distance h. What minimum amount of work must the student do to accomplish this?

(b) The valve is now opened and the lead beads tumble down the hollow tube into the other hollow sphere. If all of the gravitational potential energy is converted into thermal energy in the lead beads, what is the temperature increase of the lead?

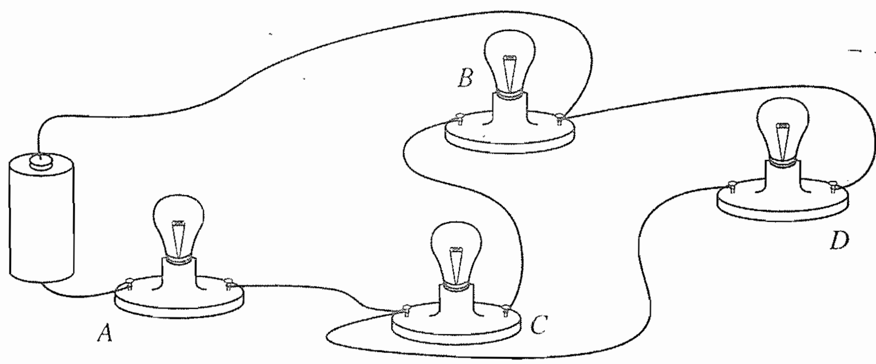
GO ON TO THE NEXT PAGE

(c) The values of M, h, and c for the students' apparatus are $M = 3.0$ kg, $h = 2.00$ m, and $c = 128$ J/(kg · K). The students measure the initial temperature of the lead beads and then conduct 100 repetitions of the "elevate-and-drain" process. Again, assume that all of the gravitational potential energy is converted into thermal energy in the lead beads. Calculate the theoretical <u>cumulative</u> temperature increase after the 100 repetitions.

(d) Suppose that the experiment were conducted using smaller reservoirs, so that M was one-tenth as large (but h was unchanged). Would your answers to parts (b) and (c) be changed? If so, in what way, and why? If not, why not?

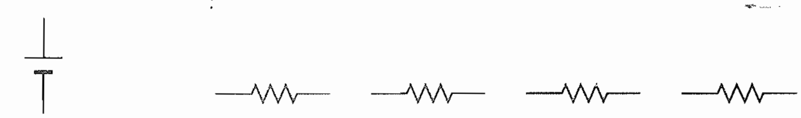
(e) When the experiment is actually done, the temperature increase is less than calculated in part (c). Identify a physical effect that might account for this discrepancy and explain why it lowers the temperature.

GO ON TO THE NEXT PAGE



4. (10 points)
In the circuit shown above, A, B, C, and D are identical lightbulbs. Assume that the battery maintains a constant potential difference between its terminals (i.e., the internal resistance of the battery is assumed to be negligible) and the resistance of each lightbulb remains constant.

(a) Draw a diagram of the circuit in the box below, using the following symbols to represent the components in your diagram. Label the resistors A, B, C, and D to refer to the corresponding lightbulbs.



Battery Resistors

Draw your diagram in this box only.

GO ON TO THE NEXT PAGE

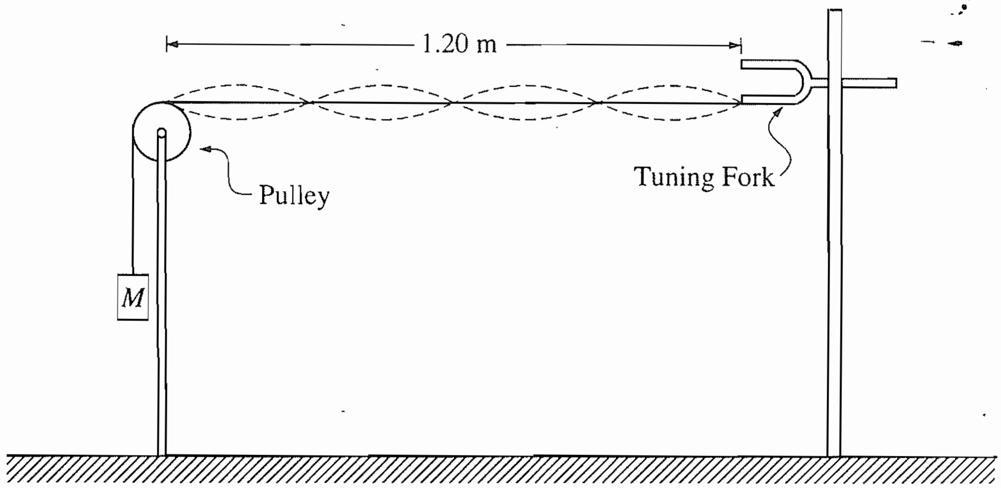
(b) List the bulbs in order of their brightnesses, from brightest to least bright. If any two or more bulbs have the same brightness, state which ones. Justify your answer.

(c) Bulb D is then removed from its socket.

i. Describe the change in the brightness, if any, of bulb A when bulb D is removed from its socket. Justify your answer.

ii. Describe the change in the brightness, if any, of bulb B when bulb D is removed from its socket. Justify your answer.

GO ON TO THE NEXT PAGE



5. (10 points)

To demonstrate standing waves, one end of a string is attached to a tuning fork with frequency 120 Hz. The other end of the string passes over a pulley and is connected to a suspended mass M as shown in the figure above. The value of M is such that the standing wave pattern has four "loops." The length of the string from the tuning fork to the point where the string touches the top of the pulley is 1.20 m. The linear density of the string is 1.0×10^{-4} kg/m, and remains constant throughout the experiment.

(a) Determine the wavelength of the standing wave.

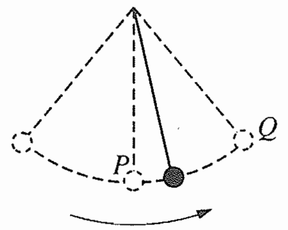
(b) Determine the speed of transverse waves along the string.

GO ON TO THE NEXT PAGE

(c) The speed of waves along the string increases with increasing tension in the string. Indicate whether the value of M should be increased or decreased in order to double the number of loops in the standing wave pattern. Justify your answer.

(d) If a point on the string at an antinode moves a total vertical distance of 4 cm during one complete cycle, what is the amplitude of the standing wave?

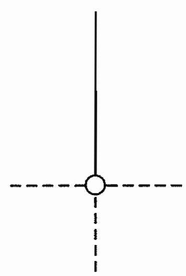
GO ON TO THE NEXT PAGE



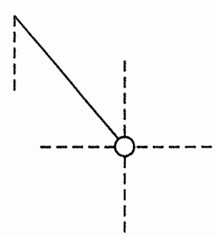
6. (10 points)
A heavy ball swings at the end of a string as shown above, with negligible air resistance. Point P is the lowest point reached by the ball in its motion, and point Q is one of the two highest points.

(a) On the following diagrams draw and label vectors that could represent the velocity and acceleration of the ball at points P and Q. If a vector is zero, explicitly state this fact. The dashed lines indicate horizontal and vertical directions.

i. Point P



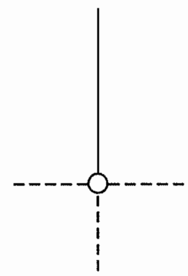
ii. Point Q



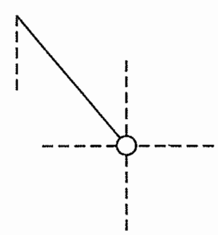
GO ON TO THE NEXT PAGE

(b) After several swings, the string breaks. The mass of the string and air resistance are negligible. On the following diagrams, sketch the path of the ball if the break occurs when the ball is at point P or point Q. In each case, briefly describe the motion of the ball after the break.

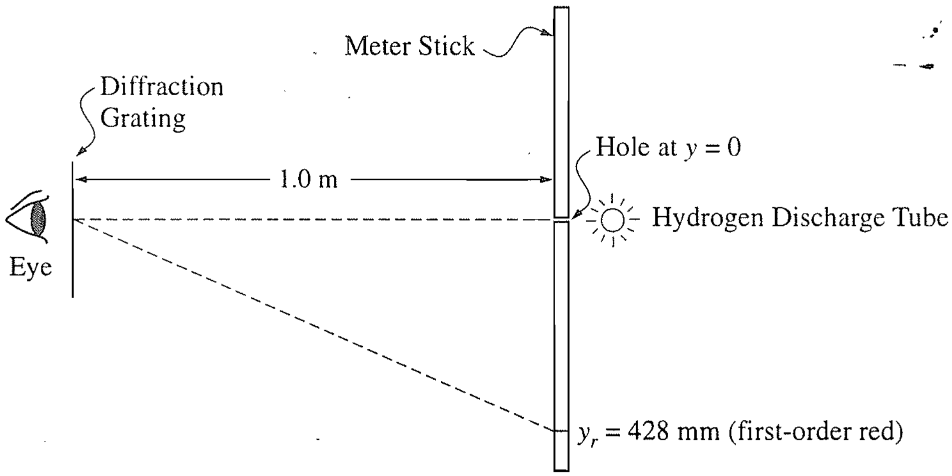
i. Point P



ii. Point Q



GO ON TO THE NEXT PAGE



Note: Figure is drawn to scale.

7. (10 points)
A transmission diffraction grating with 600 lines/mm is used to study the line spectrum of the light produced by a hydrogen discharge tube with the setup shown above. The grating is 1.0 m from the source (a hole at the center of the meter stick). An observer sees the first-order red line at a distance $y_r = 428$ mm from the hole.

(a) Calculate the wavelength of the red line in the hydrogen spectrum.

GO ON TO THE NEXT PAGE

(b) According to the Bohr model, the energy levels of the hydrogen atom are given by $E_n = -13.6\ \text{eV}/n^2$, where n is an integer labeling the levels. The red line is a transition to a final level with $n = 2$. Use the Bohr model to determine the value of n for the initial level of the transition.

(c) Qualitatively describe how the location of the first-order red line would change if a diffraction grating with 800 lines/mm were used instead of one with 600 lines/mm.

GO ON TO THE NEXT PAGE

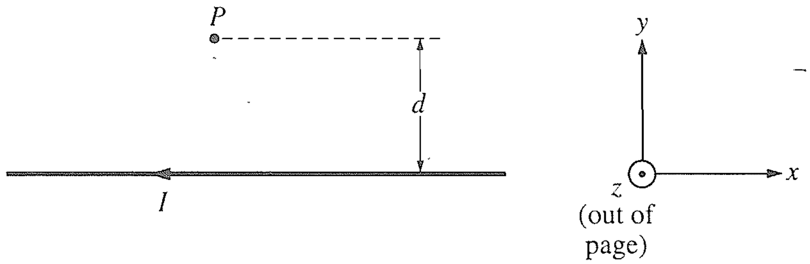


Figure 1

8. (10 points)
The long, straight wire shown in Figure 1 above is in the plane of the page and carries a current I. Point P is also in the plane of the page and is a perpendicular distance d from the wire. Gravitational effects are negligible.

(a) With reference to the coordinate system in Figure 1, what is the direction of the magnetic field at point P due to the current in the wire?

A particle of mass m and positive charge q is initially moving parallel to the wire with a speed v_0 when it is at point P, as shown in Figure 2 below.

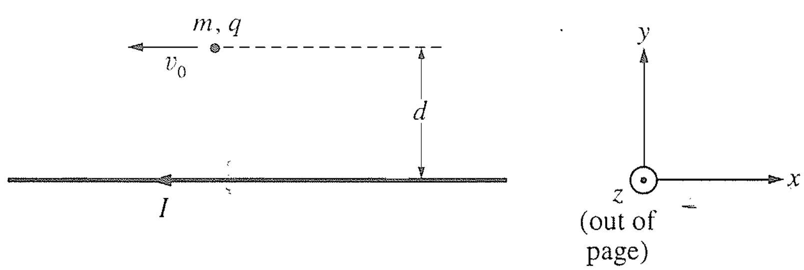


Figure 2

(b) With reference to the coordinate system in Figure 2, what is the direction of the magnetic force acting on the particle at point P ?

GO ON TO THE NEXT PAGE

(c) Determine the magnitude of the magnetic force acting on the particle at point P in terms of the given quantities and fundamental constants.

(d) An electric field is applied that causes the net force on the particle to be zero at point P.

i. With reference to the coordinate system in Figure 2, what is the direction of the electric field at point P that could accomplish this?

ii. Determine the magnitude of the electric field in terms of the given quantities and fundamental constants.

End of Examination

Chapter III Answers to the 1998 AP Physics B Examination

- Section I: Multiple Choice
  - Blank Answer Sheet
- Section II: Free Response

Section I: Multiple Choice

Listed below are the correct answers to the multiple-choice questions and the percentage of AP candidates who answered each question correctly. A copy of the blank answer sheet appears on the following pages.

Answer Key and Percent Answering Correctly

Item No.	Correct Answer	Percent Correct	Item No.	Correct Answer	Percent Correct	Item No.	Correct Answer	Percent Correct
1	B	77%	25	B	41%	48	D	39%
2	C	76%	26	B	33%	49	C	72%
3	E	70%	27	E	51%	50	D	78%
4	C	59%	28	D	43%	51	D	19%
5	C	50%	29	B	84%	52	B	45%
6	E	22%	30	D	48%	53	C	59%
7	A	71%	31	A	77%	54	B	14%
8	D	82%	32	B	84%	55	B	19%
9	A	47%	33	D	32%	56	D	38%
10	A	9%	34	B	42%	57	C	39%
11	B	59%	35	A	18%	58	C	45%
12	A	17%	36	A	79%	59	E	66%
13	A	51%	37	A	49%	60	D	30%
14	E	53%	38	D	15%	61	D	53%
15	A	66%	39	E	69%	62	C	16%
16	E	37%	40	B	23%	63	C	56%
17	C	68%	41	A	74%	64	B	24%
18	D	17%	42	E	53%	65	D	37%
19	C	32%	43	B	62%	66	C	9%
20	D	48%	44	C	53%	67	D	45%
21	A	72%	45	D	45%	68	A	50%
22	A	53%	46	A	23%	69	B	34%
23	A	59%	47	C	17%	70	E	27%
24	C	75%						

AREA 1 – COMPLETE THIS AREA AT EVERY EXAMINATION.

PLACE AP® NUMBER LABEL HERE.

A. SIGNATURE

To maintain the security of the exam and the validity of my AP grade, I will allow no one other than myself to see the multiple-choice questions and will seal the appropriate section when asked to do so. In addition, I am aware of and agree to the Program's policies and procedures as outlined in the 1998 *AP Bulletin for Students and Parents.*

Sign your name as it will appear on your college applications.

B. YOUR AP NUMBER

0 1 2 3 4 5 6 7 8 9

C. NAME Omit spaces, hyphens, apostrophes, Jr. or II.

Last Name - first 15 letters | First Name - first 12 letters | MI

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

D. ADMIN. DAY IN MAY

0 1 2 3 / 0 1 2 3 4 5 6 7 8 9

E. TIME OF DAY

6 AM, 7 AM, 8 AM, 9 AM, 10 AM, 11 AM, 12 PM, 1 PM, 2 PM, 3 PM, 4 PM, 5 PM

F. AP EXAMINATION TO BE TAKEN USING THIS ANSWER SHEET

Print examination name:

Fill in the appropriate oval below for examination name and number.

07	U.S. History	55	German Language
13	Art: History of	57	Gov. & Pol.: **U.S.**
14	Art: Studio Drawing	58	Gov. & Pol.: **Comp.**
15	Art: Studio General	59	International English Language
20	Biology	60	Latin: Vergil
25	Chemistry	60	Latin: Literature
31	Computer Science A	66	Calculus AB
33	Computer Science AB	68	Calculus BC
34	Economics: **Micro**	75	Music Theory
35	Economics: **Macro**	78	Physics B
36	Eng. Language & Comp.	80	Physics C: **Mech.**
37	Eng. Literature & Comp.	80	Physics C: **E & M**
40	Environmental Science	85	Psychology
43	European History	87	Spanish Language
48	French Language	89	Spanish Literature
51	French Literature	90	Statistics

G. What language do you know best?

- English
- English and another language about the same
- Another language

H. DO NOT COMPLETE THIS SECTION UNLESS INSTRUCTED TO DO SO.

Essay Choices
Fill in the ovals under the numbers of the essay questions you answered in this examination.

1 2 3 4 5 6 7 8 9 10 11 12

SCHOOL USE ONLY

Fee Reduction Granted | **Report to Teachers Section Designation** 1 2 3 4 5 6 7 8 9

I.N. 240045 18002 • 00657 • TF18M1300 Q2800-06 CHW97329 1 2 3 4

Answer Sheet for May 1998, Form 3UBP

Advanced Placement Program®
THE COLLEGE BOARD **PAGE 1**

AREA 2 – COMPLETE THIS AREA ONLY ONCE.

I. SEX

1 Male
2 Female

J. PRESENT GRADE LEVEL

1 9th grade
2 10th grade
3 11th grade
4 12th grade
5 College
6 Other

K. DATE OF BIRTH

Month | Day | Year

01 Jan., 02 Feb., 03 Mar., 04 Apr., 05 May, 06 June, 07 July, 08 Aug., 09 Sept., 10 Oct., 11 Nov., 12 Dec.

L. SOCIAL SECURITY NUMBER

M. ETHNIC GROUP

1 American Indian or Alaskan native
2 Black or African American
3 Mexican American or Chicano
4 Asian, Asian American, or Pacific Islander
5 Puerto Rican
6 South American, Latin American, Central American, or other Hispanic
7 White
8 Other

N. EXPECTED DATE OF COLLEGE ENTRANCE

F Fall | 8 1998
W Winter/Spring | 9 1999
S Summer | 0 2000
U Undecided | 1 2001

O. Will you be applying for Sophomore Standing at college?

Yes No

ETS USE ONLY

Exam 1 2 | Exam 1 2

P. STUDENT SEARCH SERVICE OF THE COLLEGE BOARD
(Complete ONLY if you are a SOPHOMORE or a JUNIOR.)

- Yes, I want the College Board to send information about me to colleges, universities, and governmental scholarship programs interested in students like me.
- No, I do not want the College Board to send information about me to colleges, universities, and governmental scholarship programs through the Student Search Service.

Q. THIS SECTION IS FOR THE SURVEY QUESTIONS IN THE CANDIDATE PACK. (DO NOT PUT RESPONSES TO EXAM QUESTIONS IN THIS SECTION.) BE SURE EACH MARK IS DARK AND COMPLETELY FILLS THE OVAL.

1	A	B	C	D	E	4	A	B	C	D	E
2	A	B	C	D	E	5	A	B	C	D	E
3	A	B	C	D	E						

DO NOT COMPLETE THIS SECTION UNLESS INSTRUCTED TO DO SO.

R. If this answer sheet is for the French Language, French Literature, German Language, Spanish Language, or Spanish Literature Examination, please answer the following questions. (Your responses will not affect your grade.)

1. Have you lived or studied for one month or more in a country where the language of the exam you are now taking is spoken? ◯ Yes ◯ No

2. Do you regularly speak or hear the language at home? ◯ Yes ◯ No

INDICATE YOUR ANSWERS TO THE EXAM QUESTIONS IN THIS SECTION. IF A QUESTION HAS ONLY FOUR ANSWER OPTIONS, DO NOT MARK OPTION (E). YOUR ANSWER SHEET WILL BE SCORED BY MACHINE. USE ONLY NO. 2 PENCILS TO MARK YOUR ANSWERS ON PAGES 2 AND 3 (ONE RESPONSE PER QUESTION). AFTER YOU HAVE DETERMINED YOUR RESPONSE, BE SURE TO COMPLETELY FILL IN THE OVAL CORRESPONDING TO THE NUMBER OF THE QUESTION YOU ARE ANSWERING. STRAY MARKS AND SMUDGES COULD BE READ AS ANSWERS, SO ERASE CAREFULLY AND COMPLETELY. ANY IMPROPER GRIDDING MAY AFFECT YOUR GRADE.

1	A	B	C	D	E	26	A	B	C	D	E	51	A	B	C	D	E
2	A	B	C	D	E	27	A	B	C	D	E	52	A	B	C	D	E
3	A	B	C	D	E	28	A	B	C	D	E	53	A	B	C	D	E
4	A	B	C	D	E	29	A	B	C	D	E	54	A	B	C	D	E
5	A	B	C	D	E	30	A	B	C	D	E	55	A	B	C	D	E
6	A	B	C	D	E	31	A	B	C	D	E	56	A	B	C	D	E
7	A	B	C	D	E	32	A	B	C	D	E	57	A	B	C	D	E
8	A	B	C	D	E	33	A	B	C	D	E	58	A	B	C	D	E
9	A	B	C	D	E	34	A	B	C	D	E	59	A	B	C	D	E
10	A	B	C	D	E	35	A	B	C	D	E	60	A	B	C	D	E
11	A	B	C	D	E	36	A	B	C	D	E	61	A	B	C	D	E
12	A	B	C	D	E	37	A	B	C	D	E	62	A	B	C	D	E
13	A	B	C	D	E	38	A	B	C	D	E	63	A	B	C	D	E
14	A	B	C	D	E	39	A	B	C	D	E	64	A	B	C	D	E
15	A	B	C	D	E	40	A	B	C	D	E	65	A	B	C	D	E
16	A	B	C	D	E	41	A	B	C	D	E	66	A	B	C	D	E
17	A	B	C	D	E	42	A	B	C	D	E	67	A	B	C	D	E
18	A	B	C	D	E	43	A	B	C	D	E	68	A	B	C	D	E
19	A	B	C	D	E	44	A	B	C	D	E	69	A	B	C	D	E
20	A	B	C	D	E	45	A	B	C	D	E	70	A	B	C	D	E
21	A	B	C	D	E	46	A	B	C	D	E	71	A	B	C	D	E
22	A	B	C	D	E	47	A	B	C	D	E	72	A	B	C	D	E
23	A	B	C	D	E	48	A	B	C	D	E	73	A	B	C	D	E
24	A	B	C	D	E	49	A	B	C	D	E	74	A	B	C	D	E
25	A	B	C	D	E	50	A	B	C	D	E	75	A	B	C	D	E

FOR QUESTIONS 76-151, SEE PAGE 3.

DO NOT WRITE IN THIS AREA.

Advanced Placement Program®
THE COLLEGE BOARD

PAGE 3

MULTIPLE-CHOICE BOOKLET SERIAL NUMBER
____ ____ ____ ____ ____ ____

BE SURE EACH MARK IS DARK AND COMPLETELY FILLS THE OVAL. IF A QUESTION HAS ONLY FOUR ANSWER OPTIONS, DO NOT MARK OPTION E.

76 (A) (B) (C) (D) (E)	101 (A) (B) (C) (D) (E)	126 (A) (B) (C) (D) (E)
77 (A) (B) (C) (D) (E)	102 (A) (B) (C) (D) (E)	127 (A) (B) (C) (D) (E)
78 (A) (B) (C) (D) (E)	103 (A) (B) (C) (D) (E)	128 (A) (B) (C) (D) (E)
79 (A) (B) (C) (D) (E)	104 (A) (B) (C) (D) (E)	129 (A) (B) (C) (D) (E)
80 (A) (B) (C) (D) (E)	105 (A) (B) (C) (D) (E)	130 (A) (B) (C) (D) (E)
81 (A) (B) (C) (D) (E)	106 (A) (B) (C) (D) (E)	131 (A) (B) (C) (D) (E)
82 (A) (B) (C) (D) (E)	107 (A) (B) (C) (D) (E)	132 (A) (B) (C) (D) (E)
83 (A) (B) (C) (D) (E)	108 (A) (B) (C) (D) (E)	133 (A) (B) (C) (D) (E)
84 (A) (B) (C) (D) (E)	109 (A) (B) (C) (D) (E)	134 (A) (B) (C) (D) (E)
85 (A) (B) (C) (D) (E)	110 (A) (B) (C) (D) (E)	135 (A) (B) (C) (D) (E)
86 (A) (B) (C) (D) (E)	111 (A) (B) (C) (D) (E)	136 (A) (B) (C) (D) (E)
87 (A) (B) (C) (D) (E)	112 (A) (B) (C) (D) (E)	137 (A) (B) (C) (D) (E)
88 (A) (B) (C) (D) (E)	113 (A) (B) (C) (D) (E)	138 (A) (B) (C) (D) (E)
89 (A) (B) (C) (D) (E)	114 (A) (B) (C) (D) (E)	139 (A) (B) (C) (D) (E)
90 (A) (B) (C) (D) (E)	115 (A) (B) (C) (D) (E)	140 (A) (B) (C) (D) (E)
91 (A) (B) (C) (D) (E)	116 (A) (B) (C) (D) (E)	141 (A) (B) (C) (D) (E)
92 (A) (B) (C) (D) (E)	117 (A) (B) (C) (D) (E)	142 (A) (B) (C) (D) (E)
93 (A) (B) (C) (D) (E)	118 (A) (B) (C) (D) (E)	143 (A) (B) (C) (D) (E)
94 (A) (B) (C) (D) (E)	119 (A) (B) (C) (D) (E)	144 (A) (B) (C) (D) (E)
95 (A) (B) (C) (D) (E)	120 (A) (B) (C) (D) (E)	145 (A) (B) (C) (D) (E)
96 (A) (B) (C) (D) (E)	121 (A) (B) (C) (D) (E)	146 (A) (B) (C) (D) (E)
97 (A) (B) (C) (D) (E)	122 (A) (B) (C) (D) (E)	147 (A) (B) (C) (D) (E)
98 (A) (B) (C) (D) (E)	123 (A) (B) (C) (D) (E)	148 (A) (B) (C) (D) (E)
99 (A) (B) (C) (D) (E)	124 (A) (B) (C) (D) (E)	149 (A) (B) (C) (D) (E)
100 (A) (B) (C) (D) (E)	125 (A) (B) (C) (D) (E)	150 (A) (B) (C) (D) (E)
		151 (A) (B) (C) (D) (E)

ETS USE ONLY

	R	W	FS
PT1			
PT2			
PT3			
PT4			
TOT			
EQ			
TA1			
TA2			

DO NOT WRITE IN THIS AREA.

AREA 3 – COMPLETE THIS AREA ONLY ONCE.

1. YOUR MAILING ADDRESS

- YOUR GRADE REPORT WILL BE MAILED TO THIS ADDRESS IN JULY.
- USING THE ABBREVIATIONS GIVEN IN YOUR CANDIDATE PACK, FILL ADDRESS INTO BOXES PROVIDED. IF YOUR ADDRESS DOES NOT FIT, SEE ITEM 2 BELOW.
- INDICATE A SPACE IN YOUR ADDRESS BY LEAVING A BLANK BOX AND FILLING IN THE CORRESPONDING DIAMOND (◇) BELOW THE BOX.

Street

City

STATE

1	AL	28	NE
2	AK	29	NV
3	AZ	30	NH
4	AR	31	NJ
5	CA	32	NM
6	CO	33	NY
7	CT	34	NC
8	DE	35	ND
9	DC	36	OH
10	FL	37	OK
11	GA	38	OR
12	HI	39	PA
13	ID	40	RI
14	IL	41	SC
15	IN	42	SD
16	IA	43	TN
17	KS	44	TX
18	KY	45	UT
19	LA	46	VT
20	ME	47	VA
21	MD	48	WA
22	MA	49	WV
23	MI	50	WI
24	MN	51	WY
25	MS	52	Puerto Rico
26	MO		
27	MT	53	Other

ZIP OR POSTAL CODE

1a. COUNTRY CODE

3. TELEPHONE NUMBER

Area Code

2. If the address gridded above is not complete enough for delivery of your grade report, please fill in this oval ⟶ ◯ and print your complete address below.

Address

Address

City

State or Province

Country

Zip or Postal Code

4. SCHOOL YOU ATTEND

School Code

School Name, City, and State

⟵ Make sure you have correctly entered your School Code and filled in the appropriate ovals.

School Name

City

State

5. COLLEGE TO RECEIVE YOUR AP GRADES

College Code

College Name and Address

Using the College Code list in the AP Candidate Pack, indicate the one college that has *accepted you* and that *you plan to attend.*

College Name

City

State

Section II: Free Response

On the next several pages, you will find a general analysis of each question, and the students' performance on it, by the Chief Faculty Consultant. Following these are the scoring guidelines used by the faculty consultants at the AP Reading. There are also sample student responses for each question, along with comments indicating why they received the score they did. A distribution of student scores on each free-response question appears on page 217.

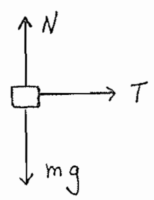
Question 1 (15 points) — Scoring Guidelines

This mechanics question uses a modification of the classic Atwood's machine arrangement of two connected masses. In a very traditional way it tests the student's understanding of Newton's laws, straight-line kinematics, and projectile motion. The different conditions before and after the hanging mass strikes the floor provide for a good test of the student's depth of understanding. The symbolic nature of the solutions provides another challenge to the less able student. Most parts of the problem could be correctly solved by more than one method. Many students were clearly not comfortable with describing physical situations verbally.

Distribution of points

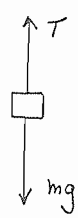
(a) 3 points

For a force diagram or a correct application of Newton's second law for block A — 1 point



OR $ma = T$

For a force diagram or a correct application of Newton's second law for block B — 1 point



OR $ma = mg - T$

Combining the two equations to eliminate T

$ma = mg - ma$

$2ma = mg$

For the correct answer — 1 point

$a = \dfrac{g}{2}$

(Alternate solution) — *(Alternate points)*

For treating the system as a one-body problem (of mass $2m$), with the proper gravitational force acting — *1 point*

For correctly applying Newton's second law — *1 point*

$2ma = mg$

For the correct answer — *1 point*

$a = \dfrac{g}{2}$

Distribution of points

Question 1 (continued)

(b) 3 points

For using the kinematic equation for distance — 1 point

$$s = s_0 + v_0 t + \frac{1}{2}at^2$$

For correctly substituting values, including the value of acceleration from part (a) — 1 point

$$h = \frac{1}{2}\left(\frac{g}{2}\right)t^2$$

For the correct answer — 1 point

$$t = 2\sqrt{\frac{h}{g}}$$

(Alternate solution) — *(Alternate points)*

For equating the work done as block B falls to the change in kinetic energy of the blocks during this time — *1 point*

$$W = \Delta K$$

$$mgh = \frac{1}{2}(2m)v^2$$

For using the kinematic equation for speed to determine the velocity of the blocks just before block B strikes the floor — *1 point*

$$v = v_0 + at$$

$$v = \frac{g}{2}t$$

Combining the two equations

$$mgh = \frac{1}{2}(2m)\left(\frac{g}{2}t\right)^2$$

$$gh = \left(\frac{g}{2}t\right)^2$$

$$\sqrt{gh} = \frac{g}{2}t$$

For the correct answer — *1 point*

$$t = 2\sqrt{\frac{h}{g}}$$

Distribution of points

Question 1 (continued)

(c) 2 points

For indicating that block A accelerates across the table | 1 point

For also having no incorrect statements about the block's motion | 1 point
(This point was only awarded if the previous point was received.)

(d) 2 points

For any indication that block A is still in motion after block B strikes the floor (e.g. referring to the block's velocity) | 1 point

For indicating that the block's velocity is constant | 1 point

One point was awarded for a statement that the velocity would decrease if friction was present

(e) 5 points

Since block B falls straight to the floor and stops, the distance between the landing points is equal to the horizontal distance of block A from the edge of the table

Determining the constant horizontal speed v at which block A travels:
For equating the work done as block B falls to the change in kinetic energy of the blocks during this time | 1 point

$W = \Delta K$

$mgh = \frac{1}{2}(2m)v^2$

For determining the velocity of the blocks just before block B strikes the floor | 1 point

$v = \sqrt{hg}$

For the correct kinematic equation for the horizontal distance x traveled by block A, with zero acceleration | 1 point

$x = vt$

Determining the time t during which block A falls:
For using the correct kinematic equation for the distance y that block A falls | 1 point

$y = y_0 + v_{0y}t + \frac{1}{2}at^2$

Question 1 (continued)

(e) (continued)

Substituting the appropriate values and solving for the time of fall

$$2h = \frac{1}{2}gt^2$$

$$t = 2\sqrt{\frac{h}{g}}$$

Substituting into the equation for x

$$x = \sqrt{hg}\left(2\sqrt{\frac{h}{g}}\right)$$

For the correct answer (consistent with values obtained for v and t) — 1 point

$$x = 2h$$

(Alternate solution for first two points) — *(Alternate points)*

For using the kinematic equation for speed to determine the velocity of the blocks just before block B strikes the floor — *1 point*

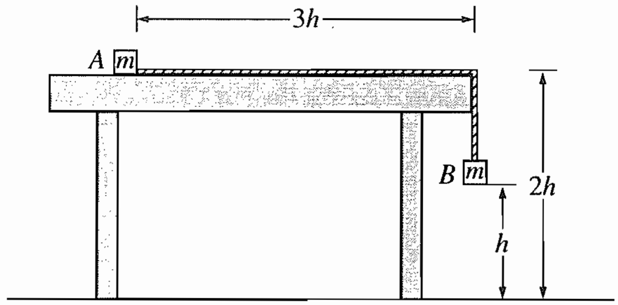
$$v = v_0 + at$$

Substituting the correct values

$$v = \frac{g}{2}\sqrt{\frac{2h}{g}}$$

For determining the velocity of the blocks just before block B strikes the floor — *1 point*

$$v = \sqrt{hg}$$



1. (15 points)
Two small blocks, each of mass m, are connected by a string of constant length $4h$ and negligible mass. Block A is placed on a smooth tabletop as shown above, and block B hangs over the edge of the table. The tabletop is a distance $2h$ above the floor. Block B is then released from rest at a distance h above the floor at time $t = 0$. Express all algebraic answers in terms of h, m, and g.

(a) Determine the acceleration of block B as it descends.

$mg - T = ma$

$T = ma$

$mg - ma = ma$

$mg = 2ma$

$\frac{\cancel{m}g}{2\cancel{m}} = a$

$a = \frac{g}{2}$

(b) Block B strikes the floor and does not bounce. Determine the time t_1 at which block B strikes the floor.

$\Delta y = v_0 t + \frac{1}{2}at^2$

$-h = 0 - \frac{1}{2}g t^2$

$h = \frac{1}{2}g t^2$

$2\frac{h}{g} = t^2$

$t_1 = \sqrt{\frac{2h}{g}}$

(c) Describe the motion of block A from time $t = 0$ to the time when block B strikes the floor.

BLOCK A WILL MOVE FROM LEFT TO RIGHT ON THE SURFACE OF THE TABLE. THE MAGNITUDE OF ACCELERATION FOR BLOCK A WILL BE EQUAL TO THE MAGNITUDE OF ACCELERATION FOR BLOCK B. $(\frac{g}{2})$.

(d) Describe the motion of block A from the time block B strikes the floor to the time block A leaves the table.

ONCE BLOCK B STRIKES THE FLOOR, BLOCK A WILL CEASE TO ACCELERATE. IT WILL CONTINUE AT A CONSTANT VELOCITY UNTIL IT REACHES THE END OF THE TABLE.

(e) Determine the distance between the landing points of the two blocks.

$at = v$

$\frac{g}{2}\left(\sqrt{\frac{2h}{g}}\right) = V_x$

$\Delta y = v_0 t + \frac{1}{2}at^2$

$-2h = -\frac{1}{2}gt^2$

$\frac{4h}{g} = t^2$

$t = 2\sqrt{\frac{h}{g}}$

$\Delta x = V_0 t + \frac{1}{2}at^2$

$\Delta x = \left(\frac{g}{2}\sqrt{\frac{2h}{g}}\right)\left(2\sqrt{\frac{h}{g}}\right)$

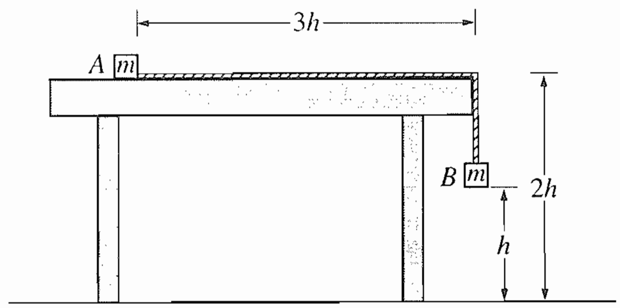
$\Delta x = \frac{\cancel{g}\sqrt{2}\sqrt{h}\,\cancel{2}\sqrt{h}}{\cancel{2}\cancel{\sqrt{g}}\cancel{\sqrt{g}}}$

$\Delta x = \sqrt{2}\,h$

$\sqrt{2}h$

Commentary:

This student does a very good job in solving the problem. The only error is in using g instead of $g/2$ in part (b). In part (e), the student uses the alternate method for determining the velocity of the blocks just before block B strikes the floor, and receives full credit for a final answer that is consistent with the incorrect time calculated in part (b).



1. (15 points)
Two small blocks, each of mass m, are connected by a string of constant length $4h$ and negligible mass. Block A is placed on a smooth tabletop as shown above, and block B hangs over the edge of the table. The tabletop is a distance $2h$ above the floor. Block B is then released from rest at a distance h above the floor at time $t = 0$. Express all algebraic answers in terms of h, m, and g.

(a) Determine the acceleration of block B as it descends.

no friction, so acceleration is g, or $9.8\,m/s^2$

(b) Block B strikes the floor and does not bounce. Determine the time t_1 at which block B strikes the floor.

$d = \frac{1}{2}at^2$

$h = \frac{1}{2}gt^2$

$t^2 = \frac{2h}{g}$

$t = \sqrt{2h/g}$

(c) Describe the motion of block A from time $t = 0$ to the time when block B strikes the floor.

The block A moves h units to the right as it is pulled by the falling block, block B.

(d) Describe the motion of block A from the time block B strikes the floor to the time block A leaves the table.

after block B strikes the ground, block A continues to move horizontally to the right at a velocity of $g\sqrt{2h/g}$; that being the velocity of block B at time of impact.

$v = at$

$v = g\left(\sqrt{2h/g}\right)$

(e) Determine the distance between the landing points of the two blocks.

$2h = \frac{1}{2}gt^2$

$t^2 = 4h/g$

$t_A = 2\sqrt{\frac{h}{g}}$

horiz. distance

$d = v(t)$

$= g\left(\sqrt{2h/g}\right)\cdot 2\sqrt{\frac{h}{g}}$

$= \cancel{g}(2\sqrt{2})\cdot\frac{h}{\cancel{g}}$

$= 2\sqrt{2}\,h$

Commentary:

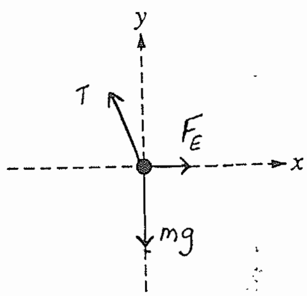
This student receives no credit for part (a), or for part (c). The remaining parts correctly calculate expressions based on the initial incorrect assumption about the acceleration, and thus receive full credit.

Question 2 (15 points) — Scoring Guidelines

The conditions of static equilibrium and the force on a charge in an electrostatic field are examined in this question. A common mistake was to treat the electric field as one that decreased with distance from the charged wall. The physical scenario of this problem makes for a somewhat unusual situation in the last part of this problem. Constant acceleration in both the horizontal and vertical directions is seldom encountered in textbook problems. As a result the last part is an excellent test of physical understanding.

Distribution of points

(a) 3 points



One point for each correctly drawn and labeled force — 3 points

One point was deducted (up to a maximum of three points) for each extra force, for any missing arrowheads, and for any missing labels

(b) 3 points

For using the correct expression for the magnitude of the electric field (as indicated by either of the following two equations) — 1 point

$E = F/q$

$E = 0.032\ \text{N}/80.0\times10^{-6}\ \text{C}$

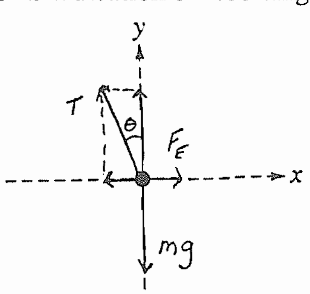
For the correct magnitude of the field — 1 point

$E = 400$ N/C

For indicating the correct direction for the field (e.g. $-x$, or to the left) — 1 point

(c) 4 points

For some indication of resolving the tension into x and y components — 1 point



For the correct force equations using these components — 1 point

$T \sin\theta = mg$

$T \cos\theta = mg$

Distribution of points

Question 2 (continued)

(c) (continued)

Dividing these equations

$$\tan\theta = \frac{F_E}{mg}$$

For determining the value of the angle θ — 1 point

$$\tan\theta = \frac{(0.032\ \text{N})}{(9.8\ \text{m/s}^2)(0.01\ \text{kg})}$$

$\theta = 18°$

Using trigonometry to find the perpendicular distance x from the wall

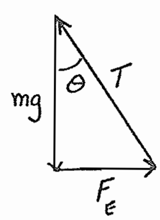
$$\sin\theta = \frac{x}{0.30\ \text{m}}$$

For the correct value for x — 1 point

$x = 0.09$ m

(Alternate solution I) — *(Alternate points)*

For some indication that the three forces are in equilibrium, e.g. drawing the triangle representing the vector addition — *1 point*



For using trigonometry to find the angle θ — *1 point*

$$\tan\theta = \frac{F_E}{mg}$$

For determining the value of the angle θ — *1 point*

$$\tan\theta = \frac{(0.032\ \text{N})}{(9.8\ \text{m/s}^2)(0.01\ \text{kg})}$$

$\theta = 18°$

Question 2 (continued)

(c) (continued)

Using trigonometry to find the perpendicular distance x from the wall

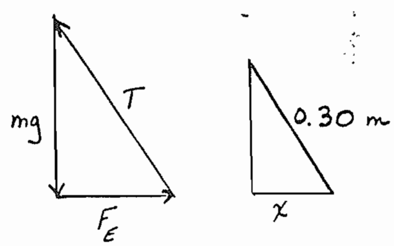
$$\sin\theta = \frac{x}{0.30\ \text{m}}$$

For the correct value for x — *1 point*

$x = 0.09$ m

(Alternate solution II) — *(Alternate points)*

For indicating both triangles to be used in the method of similar triangles — *2 points*



Calculating the length of the hypotenuse (the tension) in the force triangle

$$T = \sqrt{(0.098\ \text{N})^2 + (0.032\ \text{N})^2} = 0.103\ \text{N}$$

For correctly setting up the proportionality between the sides of the triangles — *1 point*

$$\frac{x}{0.30\text{m}} = \frac{0.032\ \text{N}}{0.103\ \text{N}}$$

For the correct answer — *1 point*

$x = 0.09$ m

Distribution of points

Question 2 (continued)

(d)

i. 4 points

For using Newton's law to calculate the acceleration due to the electric force — 1 point

$$a = \frac{F}{m} = \frac{0.032\,\text{N}}{0.01\,\text{kg}} = 3.2\ \text{m/s}^2$$

For vector addition of the two accelerations — 1 point

$$a^2 = \left(3.2\ \text{m/s}^2\right)^2 + \left(9.8\ \text{m/s}^2\right)^2$$

For the correct magnitude of the resultant acceleration — 1 point

$$a = 10.3\ \text{m/s}^2$$

Using trigonometry to calculate the angle θ

$$\tan\theta = \frac{\left(9.8\ \text{m/s}^2\right)}{\left(3.2\ \text{m/s}^2\right)}$$

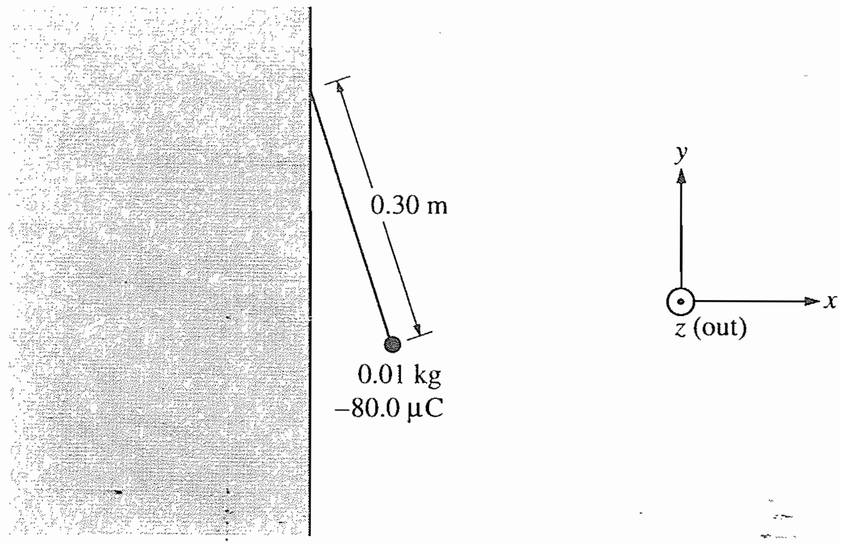
(One could also realize that the acceleration must be opposite the tension, whose angle may have been determined in part (c))

For the correct value of θ — 1 point

$\theta = 72°$ below the x-axis or $18°$ to the right of the y-axis

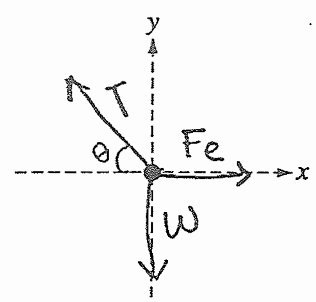
ii. 1 point

For correctly indicating that the ball moves in a straight line, down and to the right (via words or a figure), or indicating that the ball has a horizontal acceleration and a vertical acceleration due to gravity — 1 point



2. (15 points)
A wall has a negative charge distribution producing a uniform horizontal electric field. A small plastic ball of mass 0.01 kg, carrying a charge of −80.0 μC, is suspended by an uncharged, nonconducting thread 0.30 m long. The thread is attached to the wall and the ball hangs in equilibrium, as shown above, in the electric and gravitational fields. The electric force on the ball has a magnitude of 0.032 N.

(a) On the diagram below, draw and label the forces acting on the ball.



(b) Calculate the magnitude of the electric field at the ball's location due to the charged wall, and state its direction relative to the coordinate axes shown.

$F_e = qE$

$.032\,N = (-80 \times 10^{-6}\,C)\,E$

$E = -400\,N/C$

toward the left of x axis

(c) Determine the perpendicular distance from the wall to the center of the ball.

$\Sigma F_y = 0 = W - T\sin\theta = 0$

$.1N - T\sin\theta = 0$ | $.1N = T\sin\theta$

$\Sigma F_x = 0 = F_e - T\cos\theta = 0$

$.032N - T\cos\theta = 0$ | $.032N = T\cos\theta$

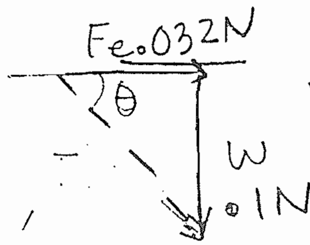
$3.125N = \tan\theta$

$\theta = 72.25°$

$\therefore S_\perp = .3m\cos(72.25°) = .09m$

(d) The string is now cut.

i. Calculate the magnitude of the resulting acceleration of the ball, and state its direction relative to the coordinate axes shown.



$F_{resultant} \approx .1N$

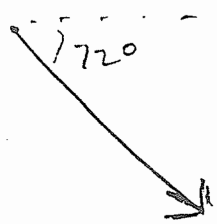
$\theta = \text{Arc}\tan\frac{.1N}{.032N} = 72.25°$

$F = ma =$

$.1N = (.01kg)a$ $a = 10m/s^2$ at $72.25°$ below x axis

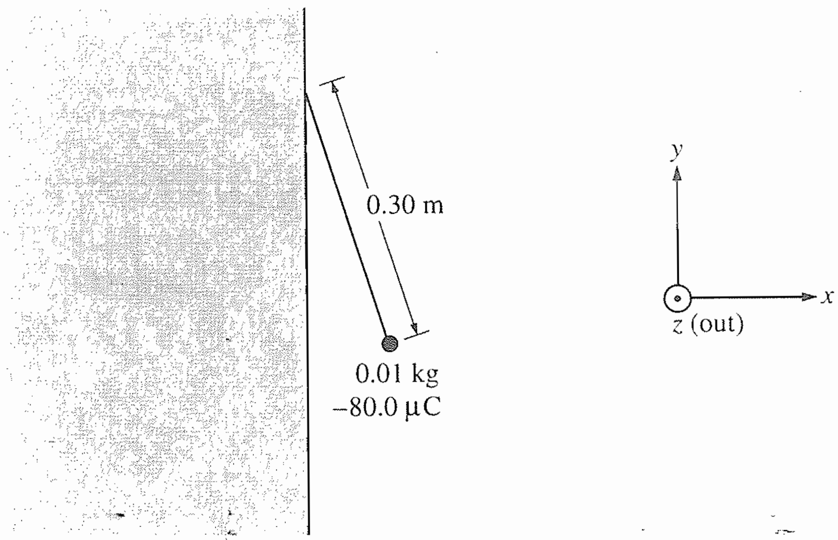
ii. Describe the resulting path of the ball.

The ball would move along a straigh path at 72.25° below x axis



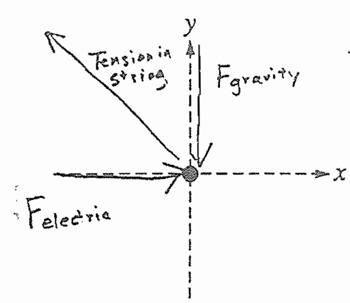
Commentary:

This student presents an extremely good solution. Note that for part (c) the student has defined θ as the larger acute angle of the triangle, so that the sine and cosine are switched when comparing these answers to the scoring guide. In part (d), the student shows an understanding of the need to add the two force vectors and then makes a reasonable approximation for the resultant force.



2. (15 points)
A wall has a negative charge distribution producing a uniform horizontal electric field. A small plastic ball of mass 0.01 kg, carrying a charge of −80.0 μC, is suspended by an uncharged, nonconducting thread 0.30 m long. The thread is attached to the wall and the ball hangs in equilibrium, as shown above, in the electric and gravitational fields. The electric force on the ball has a magnitude of 0.032 N.

(a) On the diagram below, draw and label the forces acting on the ball.



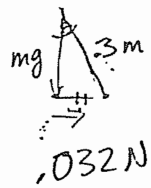
(b) Calculate the magnitude of the electric field at the ball's location due to the charged wall, and state its direction relative to the coordinate axes shown.

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

$E = \frac{.032\,N}{(-80.0 \times 10^{-6})C}$

$E = |-400\ N/C| = 400$ N/c = magnitude of E in y direction

(c) Determine the perpendicular distance from the wall to the center of the ball.



θ

$$\tan\theta = \frac{.032N}{(.01kg)(9.8)}$$

$$\theta = 18^\circ$$

$$\sin 18^\circ = \frac{x}{.3m}$$

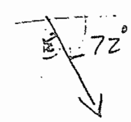
$$.09\,m = x$$

(d) The string is now cut.

i. Calculate the magnitude of the resulting acceleration of the ball, and state its direction relative to the coordinate axes shown.

$F = ma$

$T = ma$



$$\sin 18^\circ = \frac{.032N}{T}$$

$T_{ension} = .0099\,N = ma$

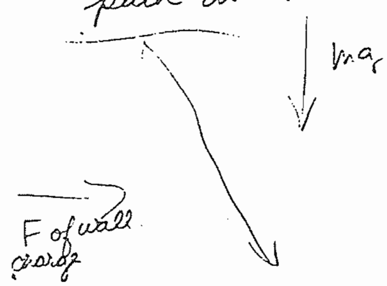
$.0099\,N = (.01)\,a$

$.99\,m/s = a$

at -72°

ii. Describe the resulting path of the ball.

it will go in a straight path at -72°



Commentary:

This student only makes two errors. The direction in part (b) is wrong. Also, an algebra error in part (d)i results in a calculation of the inverse of the tension, and thus an incorrect magnitude for the acceleration.

Question 3 (10 points) — Scoring Guidelines

This calorimetry question deals with a classic experimentally based situation, some version of which many students have probably encountered in their laboratory experience. Students are required to equate the gravitational potential energy of the lead shot to the heat gained by the shot. The last part of the question requires the student to investigate the assumptions made in the ideal treatment of the problem.

	Distribution of points
(a) 1 point	
For the correct value of work required to raise the center of mass of the lead $W = mgh$	1 point
(b) 3 points	
For a correct expression for the change in gravitational potential energy, mgh	1 point
For a correct expression for the change in thermal energy, $mc\Delta T$ This point was also awarded for using the expression $nc_V\Delta T$, but in this case the final point was <u>not</u> awarded	1 point
Equating the two energy changes $mgh = mc\Delta T$	
For the correct answer $\Delta T = \frac{gh}{c}$	1point
(c) 2 points	
For correctly substituting values in the answer to part (b) and a correct calculation	1 point
For multiplying that value by 100	1 point

$$\Delta T_{cum} = 100\frac{(9.8 \text{ m/s}^2)(2.00 \text{ m})}{128 \text{ J/kg} \bullet \text{K}}$$

$\Delta T_{cum} = 15.3 \text{ K}$ (15.6 K when using $g = 10 \text{ m/s}^2$.)

(d) 2 points	
The answers to parts (b) and (c) will not change, because ΔT does not depend on the mass.	
For correctly saying "no" and including a correct physical explanation	2 points
Full credit was awarded for "yes" plus an explanation if this was consistent with student's answers to (b) and (c).	

Distribution of points

Question 3 (continued)

(e) 2 points

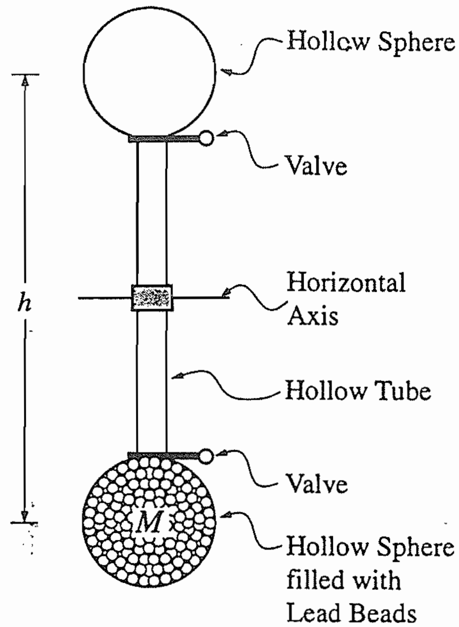
For any completely correct answer referring to energy transfer — 2 points

For example: There is friction between the lead and the apparatus, resulting in a loss of heat to the surroundings.

Only one point was awarded for an answer that had a correct reference to energy transfer but also had incorrect statements.

Only one point was awarded for a correct answer without elaboration, for example, "Friction", "Air resistance", or "Time elapsed"

Excellent Student Response: 10 points



3. (10 points)
Students are designing an experiment to demonstrate the conversion of mechanical energy into thermal energy. They have designed the apparatus shown in the figure above. Small lead beads of total mass M and specific heat c fill the lower hollow sphere. The valves between the spheres and the hollow tube can be opened or closed to control the flow of the lead beads. Initially both valves are open.

(a) The lower valve is closed and a student turns the apparatus 180° about a horizontal axis, so that the filled sphere is now on top. This elevates the center of mass of the lead beads by a vertical distance h. What minimum amount of work must the student do to accomplish this?

Student gives sphere potential energy $\therefore W = PE = Mgh$

$\therefore$ the work done is Mgh

(b) The valve is now opened and the lead beads tumble down the hollow tube into the other hollow sphere. If all of the gravitational potential energy is converted into thermal energy in the lead beads, what is the temperature increase of the lead?

$PE = Mgh \qquad Q = Mc\Delta T \qquad PE = Q \;\therefore$

$\cancel{M}gh = \cancel{M}c\Delta T \qquad gh = c\Delta T \qquad \Delta T = \frac{gh}{c}$

(c) The values of M, h, and c for the students' apparatus are $M = 3.0$ kg, $h = 2.00$ m, and $c = 128$ J/(kg · K). The students measure the initial temperature of the lead beads and then conduct 100 repetitions of the "elevate-and-drain" process. Again, assume that all of the gravitational potential energy is converted into thermal energy in the lead beads. Calculate the theoretical cumulative temperature increase after the 100 repetitions.

$\Delta T = \frac{gh}{c}$ (from part b) $\therefore$ $\Delta T = \frac{9.8\,m/s^2 \cdot 2\,m}{128\ J/kg \cdot K}$

$\Delta T = .153125\ K$

$\Delta T_{cumulative} = \Delta T \cdot 100 = .153125K \cdot 100 = 15.3125\ K$

(d) Suppose that the experiment were conducted using smaller reservoirs, so that M was one-tenth as large (but h was unchanged). Would your answers to parts (b) and (c) be changed? If so, in what way, and why? If not, why not?

No, they would not change

Potential Energy and the heat added are both directly proportional to the mass

$PE = Mgh = Mc\Delta T = Q$ $\quad \cancel{M}gh = \cancel{M}c\Delta T$ Any change in mass will not effect the change in Temperature

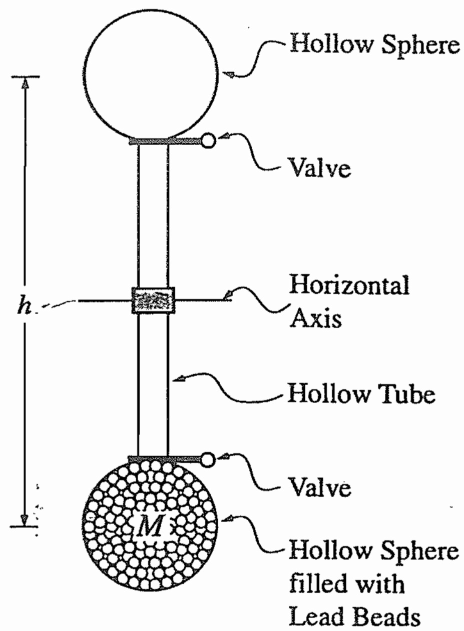
(e) When the experiment is actually done, the temperature increase is less than calculated in part (c). Identify a physical effect that might account for this discrepancy and explain why it lowers the temperature.

Heat transfer

Heat would be transferred from the beads to the aparatus and from there to the air. Heat will then be lost

Commentary:

This student provides clear and complete answers to all parts of the problem.



3. (10 points)
Students are designing an experiment to demonstrate the conversion of mechanical energy into thermal energy. They have designed the apparatus shown in the figure above. Small lead beads of total mass M and specific heat c fill the lower hollow sphere. The valves between the spheres and the hollow tube can be opened or closed to control the flow of the lead beads. Initially both valves are open.

(a) The lower valve is closed and a student turns the apparatus 180° about a horizontal axis, so that the filled sphere is now on top. This elevates the center of mass of the lead beads by a vertical distance h. What minimum amount of work must the student do to accomplish this?

$W = F \cdot \text{distance}$

$W = Ma \cdot h \quad a = g$

$w = mgh$

(b) The valve is now opened and the lead beads tumble down the hollow tube into the other hollow sphere. If all of the gravitational potential energy is converted into thermal energy in the lead beads, what is the temperature increase of the lead?

$Q = \cancel{M} c \Delta T = \cancel{M} gh$

$\Delta T = \frac{gh}{c}$

(c) The values of M, h, and c for the students' apparatus are $M = 3.0$ kg, $h = 2.00$ m, and $c = 128$ J/(kg • K). The students measure the initial temperature of the lead beads and then conduct 100 repetitions of the "elevate-and-drain" process. Again, assume that all of the gravitational potential energy is converted into thermal energy in the lead beads. Calculate the theoretical cumulative temperature increase after the 100 repetitions.

$$\Delta T = \frac{(10\frac{m}{s^2})(2m)}{128} = .16°K \quad \times 100 \text{reps} = \boxed{16°K}$$

(d) Suppose that the experiment were conducted using smaller reservoirs, so that M was one-tenth as large (but h was unchanged). Would your answers to parts (b) and (c) be changed? If so, in what way, and why? If not, why not?

they would have remained the same because there would still be the same change in temperature, regardless of mass

(e) When the experiment is actually done, the temperature increase is less than calculated in part (c). Identify a physical effect that might account for this discrepancy and explain why it lowers the temperature.

Not all of the potential energy would have been converted into thermal energy. Some may have been converted to kinetic energy, or possibly there could have been friction with the tube going down.

Commentary:

This student gets all the calculational parts correct, but has incomplete explanations for the last two parts.

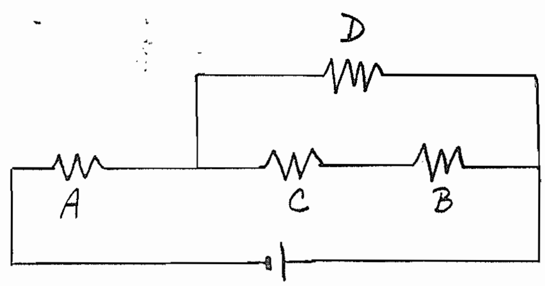
Question 4 (10 points) — Scoring Guidelines

This DC circuit question is completely qualitative, requiring no numerical calculations. To successfully complete this question the student is required to demonstrate a good understanding of Ohm's law, the electrical power's dependence on voltage and current, and the characteristics of series and parallel connections of circuit elements.

Distribution of points

(a) 3 points

Draw your diagram in this box only.



For connecting bulbs A, B, and C end to end, in the correct order	1 point
For connecting bulb D in parallel across both B and C	1 point
For connecting the battery so that current exists in all four bulbs	1 point

(b) 3 points

For indicating that bulb A is brightest, and bulb D is brighter than both bulb B and C	1 point
For indicating that bulbs B and C have the same brightness	1 point
For correct justifications	1 point

For example, bulb A has the largest current through it, making it brightest. The voltage across bulb D is the same as that across bulbs B and C combined, so it is next brightest, leaving B and C as least bright. Bulbs B and C are in series, and thus have the same current through them, so they must be equally bright.

Distribution of points

Question 4 (continued)

(c)
i. 2 points

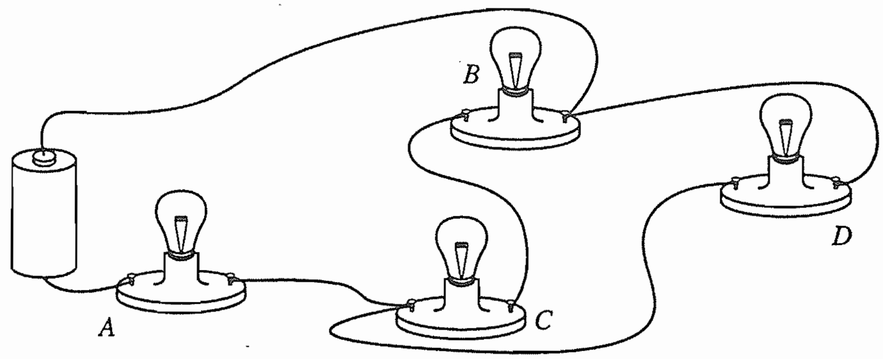
For indicating that the brightness of bulb A decreases — 1 point

For a correct justification — 1 point
For example: The total resistance of the circuit increases, so the current in bulb A decreases

ii. 2 points

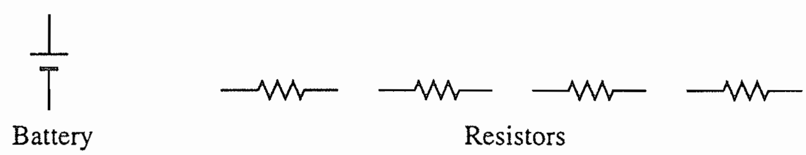
For indicating that the brightness of bulb B increases — 1 point

For a correct justification — 1 point
For example: The current in bulb B increases, or the voltage across it increases

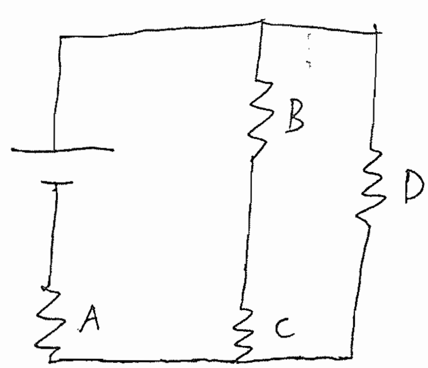


4. (10 points)
In the circuit shown above, A, B, C, and D are identical lightbulbs. Assume that the battery maintains a constant potential difference between its terminals (i.e., the internal resistance of the battery is assumed to be negligible) and the resistance of each lightbulb remains constant.

(a) Draw a diagram of the circuit in the box below, using the following symbols to represent the components in your diagram. Label the resistors A, B, C, and D to refer to the corresponding lightbulbs.



Draw your diagram in this box only.



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

→ A is the brightest, because all of the current must flow through it.

D is in parallel with B and C.

since there is equal voltage across D and B&C, but D alone has less resistance than B and C, more current flows through D, so
→ D is the second brightest.

B and C are in series, so they have the same current. Therefore,

→ B and C are the least bright, but are equal to each other.

(c) Bulb D is then removed from its socket.

i. Describe the change in the brightness, if any, of bulb A when bulb D is removed from its socket. Justify your answer.

A is less bright because the overall resistance of the circuit increases, causing the current to decrease.

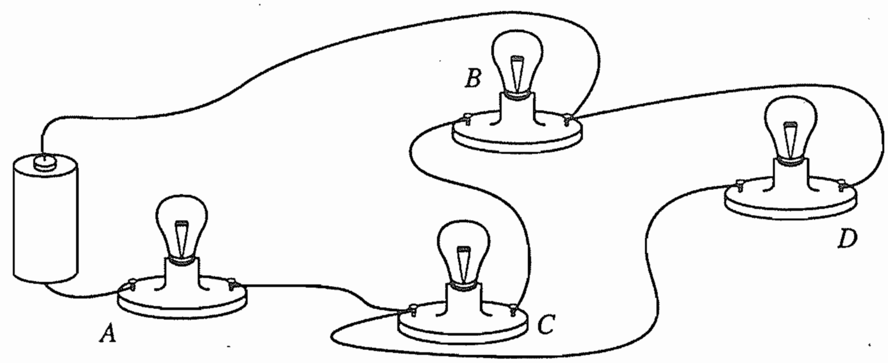
ii. Describe the change in the brightness, if any, of bulb B when bulb D is removed from its socket. Justify your answer.

B is brighter because it is now in series instead of parallel, and all of the current must flow through it.

Commentary:

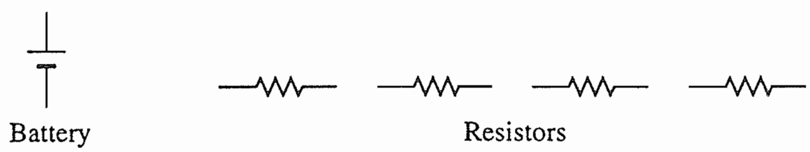
This student gives explanations for the correct answers that are both clear and organized. The circuit diagram is drawn such that a clear comparison with the given figure can be made.

Very Good Student Response: 8 points

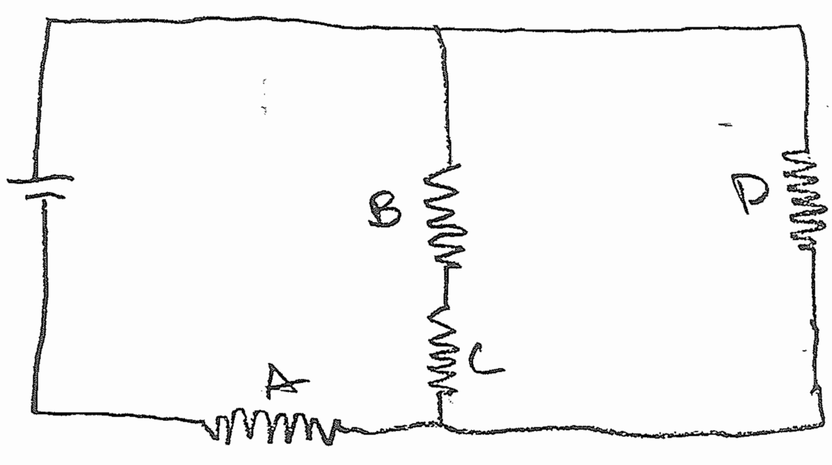


4. (10 points)
In the circuit shown above, A, B, C, and D are identical lightbulbs. Assume that the battery maintains a constant potential difference between its terminals (i.e., the internal resistance of the battery is assumed to be negligible) and the resistance of each lightbulb remains constant.

(a) Draw a diagram of the circuit in the box below, using the following symbols to represent the components in your diagram. Label the resistors A, B, C, and D to refer to the corresponding lightbulbs.



Draw your diagram in this box only.



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

A is brightest - all of the current flows through it

D is second since more current passes through its branch of the circuit than the other because it has a smaller resistance

B and C both have the least and the same because they are in series and therefore have the same current.

(c) Bulb D is then removed from its socket.

i. Describe the change in the brightness, if any, of bulb A when bulb D is removed from its socket. Justify your answer.

The brightness of bulb A should not change since the same amount of current will be running through it.

ii. Describe the change in the brightness, if any, of bulb B when bulb D is removed from its socket. Justify your answer.

bulb B will be brighter because it will get the full current through it, Not the partial one since there will be no ~~D~~ to draw current on an alternate path

Commentary:

This student's answers are as clear and well organized as the previous paper. However, this student misses the fact that removing bulb D affects the total current in the circuit, and gets part (c)i wrong.

Question 5 (10 points) — Scoring Guidelines

In recent years assessment of student understanding of waves has been primarily accomplished by inclusion of an optics problem involving interference of some sort. In this question the conditions for production of standing waves in a string under tension are investigated. The question is very straightforward, and most students did well on it with the exception of the last part, which required a very careful reading in order to be answered correctly. While specifically intended to see if students understood how the point corresponding to an antinode in a standing wave moved, the widespread misinterpretation of the reference to the distance moved was neither intended nor anticipated. Part (c) tested knowledge of the dependencies of the relevant variables without requiring the student to recall the equation for the velocity of a wave on a string under tension.

Distribution of points

(a) 2 points

Using a relationship between the wavelength λ and the length L of the string, for example the general relationship $\lambda = \frac{2L}{n}$, where n is the number of loops in the standing wave pattern, or the specific relationship for this case $2\lambda = L$ which can be developed directly from information in the question

For correct substitution of values — 1 point

$\lambda = \frac{2(1.20\ \text{m})}{4}$

For the correct answer — 1 point

$\lambda = 0.60\ \text{m}$

(b) 2 points

Using the relationship for the speed of a wave

$v = \nu\lambda$

For correct substitution of values — 1 point

$v = (120\ \text{Hz})(0.60\ \text{m})$

For the correct answer — 1 point

$v = 72\ \text{m/s}$

(c) 3 points

For indicating that the mass should be decreased — 1 point

For any two of the statements in the following explanation, one point each — 2 points

- The wavelength must decrease for there to be more loops on the string
- Given that the frequency is constant, the speed of the waves must decrease if the wavelength does
- This means that the tension must decrease, so the mass must be decreased

Distribution
of points

Question 5 (continued)

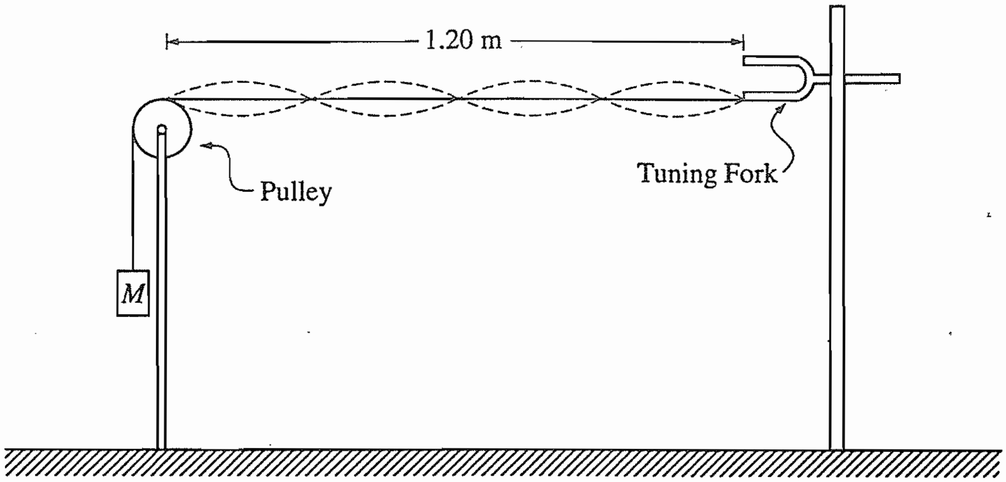
(d) 2 points

In one complete cycle, a point on the string begins at some position and travels until it returns to that position. For example, a point at an antinode that is at its highest point at the beginning of the cycle travels to its lowest point, and then back to the highest point. The amplitude of the standing wave is the distance from the center point (where the string would be straight) to one of these extremes, or one fourth the distance traveled.

For the correct answer | 2 points
Amplitude = 1 cm

One point was awarded for answering 2 cm, which is the result of interpreting "total vertical distance" as the distance between the highest and lowest points of the antinode and then correctly calculating an amplitude of 2 cm based on that interpretation.

For having all units on answers correct | 1 point



5. (10 points)
To demonstrate standing waves, one end of a string is attached to a tuning fork with frequency 120 Hz. The other end of the string passes over a pulley and is connected to a suspended mass M as shown in the figure above. The value of M is such that the standing wave pattern has four "loops." The length of the string from the tuning fork to the point where the string touches the top of the pulley is 1.20 m. The linear density of the string is 1.0×10^{-4} kg/m, and remains constant throughout the experiment.

(a) Determine the wavelength of the standing wave.

$$\lambda = \frac{\text{length}}{\text{\# of waves}}$$

$$\lambda = \frac{1.2\,m}{2}$$

$$\lambda = .6\,m$$

(b) Determine the speed of transverse waves along the string.

$$V = \lambda f$$

$$= (.6)(120)$$

$$= 72\ m/sec$$

(c) The speed of waves along the string increases with increasing tension in the string. Indicate whether the value of M should be increased or decreased in order to double the number of loops in the standing wave pattern. Justify your answer.

If M is decreased! Then to keep it is equilibrium, the tension would decrease ∴ A decrease in tension would decrease the speed of the waves as stated and since frequency is constant, wave length would decrease; A decreased wavelenth means more loops in 1.2m of rope.

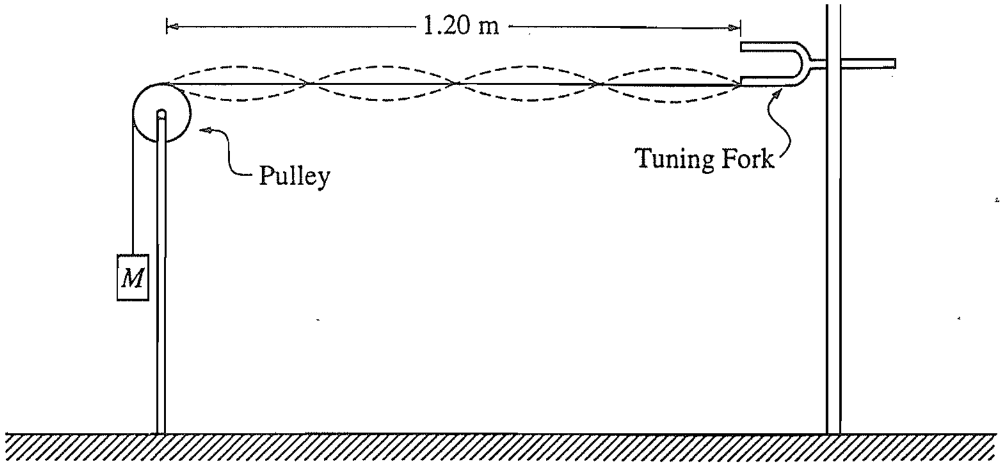
(d) If a point on the string at an antinode moves a total vertical distance of 4 cm during one complete cycle, what is the amplitude of the standing wave?

1cm ↑ 2cm ↓ ↑1cm = 4cm

$\boxed{\text{amplitude} = 1\text{cm}}$

Commentary:

This student gives a complete, logical explanation for part (c) that can be easily followed. The arrows drawn in part (d) indicate that the student understands the motion being described.



5. (10 points)
To demonstrate standing waves, one end of a string is attached to a tuning fork with frequency 120 Hz. The other end of the string passes over a pulley and is connected to a suspended mass M as shown in the figure above. The value of M is such that the standing wave pattern has four "loops." The length of the string from the tuning fork to the point where the string touches the top of the pulley is 1.20 m. The linear density of the string is 1.0×10^{-4} kg/m, and remains constant throughout the experiment.

(a) Determine the wavelength of the standing wave.

$\lambda = \frac{1.20\,m}{2\,cycles} = 0.60\,m$

(b) Determine the speed of transverse waves along the string.

$\cancel{v} = f\lambda$

$v = (120\,Hz)(0.60\,m) = 72\,m/s$

(c) The speed of waves along the string increases with increasing tension in the string. Indicate whether the value of M should be increased or decreased in order to double the number of loops in the standing wave pattern. Justify your answer.

The value of M should be decreased to decrease the tension.

$V = f\lambda$

$\lambda = \frac{f}{V}$

$T = (M)g$

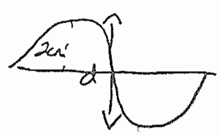
$T \propto M$

$T \propto V$

$\lambda \propto \frac{1}{V}$

(d) If a point on the string at an antinode moves a total vertical distance of 4 cm during one complete cycle, what is the amplitude of the standing wave?

The amplitude of the wave is 2cm.



$d = 4cm$

Commentary:

This student is missing one additional statement needed to receive full credit for part (c). Part (d) is an example of the many answers that showed an understanding of amplitude, but a misinterpretation of the description of the string's motion.

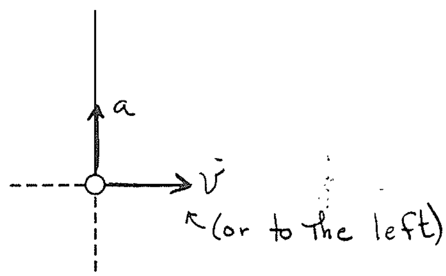
Question 6 (10 points) — Scoring Guidelines

This question deals with the variation of the velocity and acceleration of a mass on the end of a string as it swings as a pendulum. While requiring no numerical calculation, this question proved difficult for many students. It is an excellent test of physical understanding. Performance on this question indicates that many students are not yet comfortable with giving accurate verbal descriptions of a physical phenomenon. A common mistake was to interchange the correct motions in parts (b)-i and (b)-ii, revealing a persisting Aristotelian conception of motion.

Distribution of points

(a)

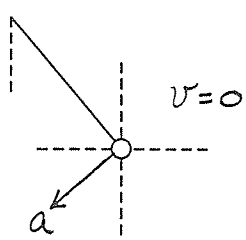
i. 2 points



For a correctly drawn velocity vector, directed along the horizontal line, either to the right or the left	1 point
For the correctly drawn acceleration vector, directed upward along the string	1 point

Vectors must be labeled, and have an arrowhead to show their direction

ii. 3 points



For indicating that the velocity is zero	1 point
For the correctly drawn acceleration vector, pointing down and to the left, perpendicular to the string	2 points

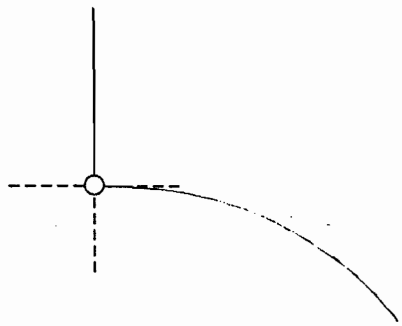
One of these points was awarded if the vector was in the proper quadrant, not perpendicular to the string, and not on either the vertical or horizontal lines

Distribution of points

Question 6 (continued)

(b)

i. 3 points



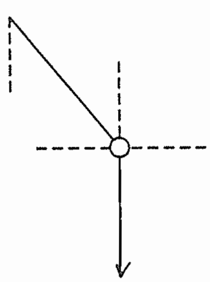
(A path drawn to the left is also correct)

For indicating that the path is initially horizontal (via figure or words)	1 point
For indicating that the horizontal velocity is constant	1 point
For indicating that the vertical motion is under constant acceleration or free-fall	1 point

The last two points were also awarded for describing the path as a parabola, or indicating that the ball is a projectile

A maximum of 2 points were awarded for a correct figure with no description or a correct description with no path drawn on the figure

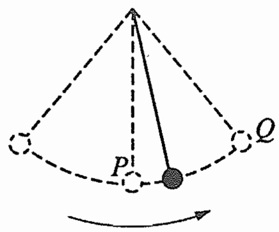
ii. 2 points



For correctly indicating that the ball falls straight down	1 point
For indicating that the vertical motion is under constant acceleration or free-fall	1 point

A maximum of 1 point was awarded for a correct figure with no description or a correct description with no path drawn on the figure

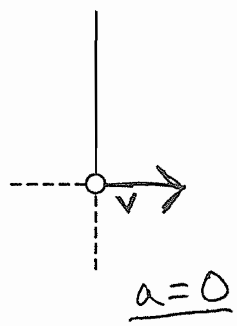
Very Good Student Response: 9 points



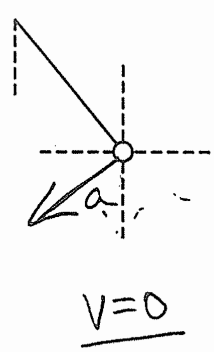
6. (10 points)
A heavy ball swings at the end of a string as shown above, with negligible air resistance. Point P is the lowest point reached by the ball in its motion, and point Q is one of the two highest points.

(a) On the following diagrams draw and label vectors that could represent the velocity and acceleration of the ball at points P and Q. If a vector is zero, explicitly state this fact. The dashed lines indicate horizontal and vertical directions.

i. Point P

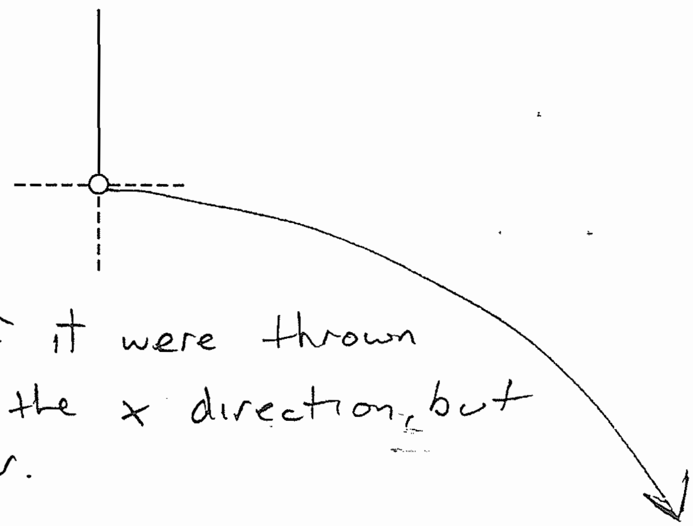


ii. Point Q



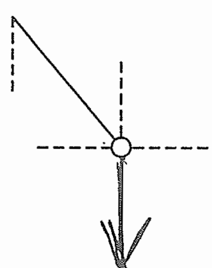
(b) After several swings, the string breaks. The mass of the string and air resistance are negligible. On the following diagrams, sketch the path of the ball if the break occurs when the ball is at point P or point Q. In each case, briefly describe the motion of the ball after the break.

i. Point P



The ball would act as if it were thrown right at a certain velocity in the x direction, but no initial velocity in the y-dir.

ii. Point Q

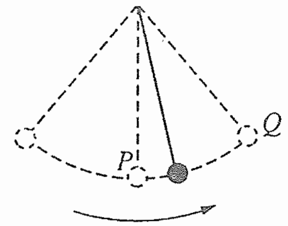


The ball would fall straight down, because at this point its velocity is 0, and its acceleration is ↓, due only to gravity.

Commentary:

Given the correct acceleration vector in (a)ii and the error in (a)i, this student may be thinking only of tangential acceleration. The explanation in (b)i qualifies as describing the ball as a projectile.

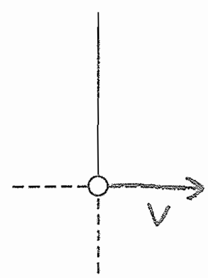
Good Student Response: 7 points



6. (10 points)
A heavy ball swings at the end of a string as shown above, with negligible air resistance. Point P is the lowest point reached by the ball in its motion, and point Q is one of the two highest points.

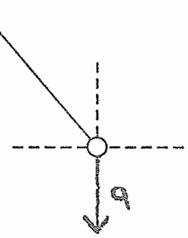
(a) On the following diagrams draw and label vectors that could represent the velocity and acceleration of the ball at points P and Q. If a vector is zero, explicitly state this fact. The dashed lines indicate horizontal and vertical directions.

i. Point P



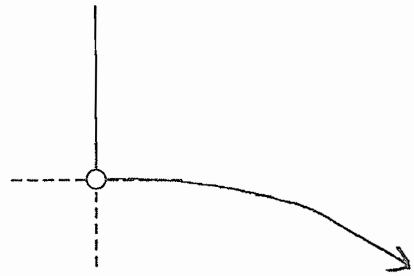
ii. Point Q

Velocity=0



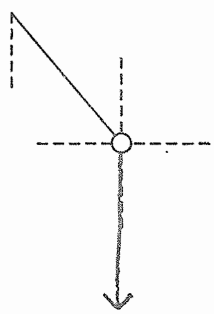
(b) After several swings, the string breaks. The mass of the string and air resistance are negligible. On the following diagrams, sketch the path of the ball if the break occurs when the ball is at point P or point Q. In each case, briefly describe the motion of the ball after the break.

i. Point P



The ball will travel in a parabolic downward arc due to its velocity and the acceleration of gravity.

ii. Point Q



The ball has no velocity, so it will merely fall straight down due to gravity.

Commentary:

This student appears to be treating both cases the same, as if the string breaks, and thus receives only two points for part (a). However, part (b) receives full credit.

Question 7 (10 points) — Scoring Guidelines

This question examines understanding of both diffraction by a grating and the hydrogen spectrum, using an arrangement that is more typically found in a laboratory situation than in a textbook problem. To correctly answer the first part of the problem the student must use the equation giving the locations of the maxima produced by a diffraction grating. The small angle approximation that is heavily emphasized in textbook examples is not applicable under the conditions of this problem. The mean score on this question was the lowest on the exam, no doubt due in part to the somewhat unusual nature of the problem and in part to the inclusion of some atomic physics, which many students have not covered.

	Distribution of points
(a) 4 points	
Using the expression for the location of lines in the diffraction pattern $d \sin\theta = m\lambda$	
For using the correct value for d $d = \dfrac{1}{600 \text{ lines/mm}} = 1.67 \times 10^{-6} \text{ m}$	1 point
For finding the value of θ, the angle between the two dashed lines in the figure $\tan\theta = \dfrac{y}{L} = \dfrac{428 \text{ mm}}{1.0 \text{ m}}$ $\theta = 23°$	1 point
For correct substitutions into the first equation $(1.67 \times 10^{-6} \text{ m}) \sin 23° = (1)\lambda$	1 point
For the correct answer $\lambda = 657 \text{ nm}$ or $6.57 \times 10^{-7} \text{ m}$	1 point
If the small angle approximation was used ($\sin\theta \approx \tan\theta$, resulting in an answer of 713 nm), the point for finding the angle was <u>not</u> awarded	
(b) 4 points	
For using the correct equation(s) relating energy and wavelength $E = \dfrac{hc}{\lambda}$ OR $E = h\nu$ and $c = \nu\lambda$	1 point
Substituting $E = \dfrac{(1.24 \times 10^{3} \text{ eV} \bullet \text{nm})}{657 \text{ nm}}$ OR $E = \dfrac{(1.99 \times 10^{-25} \text{ J} \bullet \text{m})}{657 \text{ nm}}$	
For the correct photon energy $E = 1.89 \text{ eV}$ OR $3.03 \times 10^{-19} \text{ J}$ Credit was also awarded for an energy consistent with a wrong answer for part (a), for example, using 713 nm and obtaining 1.74 eV or 2.79×10^{-19} J	1 point

Distribution
of points

Question 7 (continued)

(b) (continued)

For some indication that this photon energy is the difference between two energy levels For example, a statement on conservation of energy, an energy level diagram, a statement saying the photon energy is the energy released when an electron drops to a lower energy level, or an equation involving the appropriate energies — 1 point

Using the energy-level equation

$$E = E_n - E_2$$

$$1.89 \text{ eV} = (-13.6 \text{ eV})\left(\frac{1}{n^2} - \frac{1}{2^2}\right)$$

$$-0.14 = \left(\frac{1}{n^2} - \frac{1}{4}\right)$$

$$0.11 = \frac{1}{n^2}$$

$$n^2 = 9.1$$

For the correct answer — 1 point

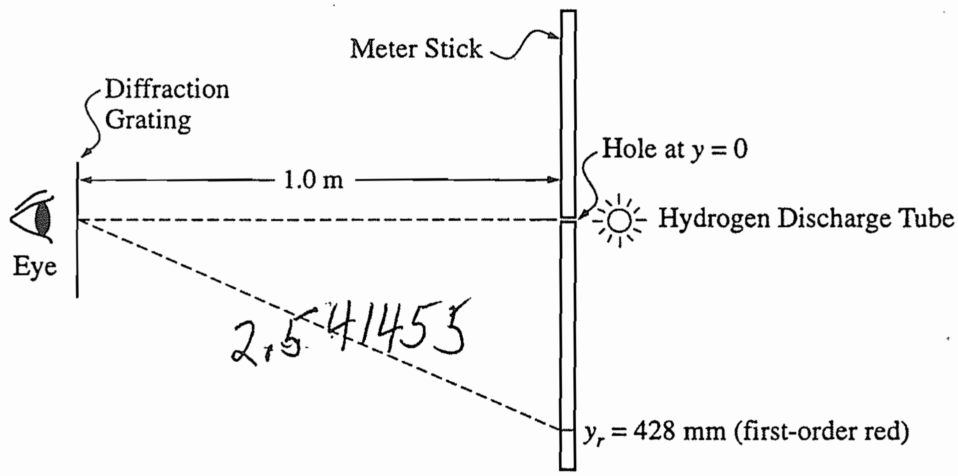
$n = 3$

Full credit was earned using 713 nm (resulting in $n = 2.86$) if the student realized that n must be an integer and indicated $n = 3$

Three points were awarded for an answer of $n = 3$ with no work shown

(c) 2 points

For any reasonable indication that the line would move farther away from the principal axis — 2 points



Note: Figure is drawn to scale.

7. (10 points)
A transmission diffraction grating with 600 lines/mm is used to study the line spectrum of the light produced by a hydrogen discharge tube with the setup shown above. The grating is 1.0 m from the source (a hole at the center of the meter stick). An observer sees the first-order red line at a distance y_r = 428 mm from the hole.

(a) Calculate the wavelength of the red line in the hydrogen spectrum.

$d \sin\theta = m\lambda$

$\lambda = \frac{1}{600}\text{mm} \sin(\tan^{-1} .428)$

6.56×10^{-7} m

(b) According to the Bohr model, the energy levels of the hydrogen atom are given by $E_n = -13.6\ \text{eV}/n^2$, where n is an integer labeling the levels. The red line is a transition to a final level with $n = 2$. Use the Bohr model to determine the value of n for the initial level of the transition.

$f\lambda = c$

$n = 3$

$f = \frac{c}{\lambda}$

$E = fh = \frac{ch}{\lambda}$

$\frac{ch}{\lambda} = \frac{13.6\,eV}{4} - \frac{13.6\,eV}{n^2}$

$1.89\,eV = 13.6\,eV\left(\frac{1}{4} - \frac{1}{n^2}\right)$

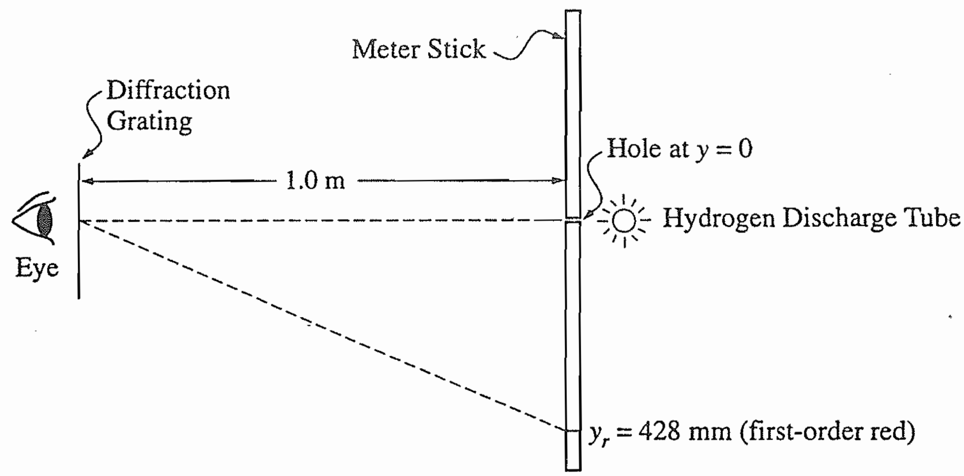
$.13897 = \frac{1}{4} - \frac{1}{n^2}$

(c) Qualitatively describe how the location of the first-order red line would change if a diffraction grating with 800 lines/mm were used instead of one with 600 lines/mm.

If the lines were closer together $\sin\theta$ would need to be bigger to keep $d\sin\theta$ constant. Thus, the first-order red line would be farther than .142m from the source

Commentary:

This student packs a lot of physics and geometry into deriving the second line of part (a) from the initial equation. The remaining parts are clear and organized.



Note: Figure is drawn to scale.

7. (10 points)
A transmission diffraction grating with 600 lines/mm is used to study the line spectrum of the light produced by a hydrogen discharge tube with the setup shown above. The grating is 1.0 m from the source (a hole at the center of the meter stick). An observer sees the first-order red line at a distance $y_r = 428$ mm from the hole.

(a) Calculate the wavelength of the red line in the hydrogen spectrum.

$$X_m = \frac{m \lambda L}{d}$$

$$428 \text{ mm} = \frac{(1)(\lambda)(1000 \text{ mm})}{.00167 \text{ mm}}$$

$$\lambda = \left(\frac{(428)(.00167)}{1000} \right) \text{mm}$$

$$\lambda = 7.1333 \times 10^{-4} \text{ mm} \quad \frac{10^{-3} \text{ m}}{1 \text{ mm}}$$

$$\boxed{\lambda = 7.1333 \times 10^{-7} \text{ m}}$$

(b) According to the Bohr model, the energy levels of the hydrogen atom are given by $E_n = -13.6\ \text{eV}/n^2$, where n is an integer labeling the levels. The red line is a transition to a final level with $n = 2$. Use the Bohr model to determine the value of n for the initial level of the transition.

$n = 2.79$ ———— $1.738\ eV$

$n = 2$ ———— $-3.4\ eV$

$n = 1$ ———— $-13.6\ eV$

$$E_2 = \frac{-13.6\ ev}{(2)^2}$$

$$E_2 = -3.4\ eV$$

$$E_x = \frac{hc}{\lambda} = \frac{-13.6}{x^2}$$

$$hcx^2 = (-13.6)(713\ nm)$$

$$x^2 = 7.82$$

$$x = \pm 2.79$$

$$\boxed{n = 3}$$

(c) Qualitatively describe how the location of the first-order red line would change if a diffraction grating with 800 lines/mm were used instead of one with 600 lines/mm.

The location of the red line would be farther from $(y=0)$ because the distance between slits would be smaller and $\left(x_m = \frac{m\lambda L}{d}\right)$ would produce a larger x_m.

shown: $x_m = \frac{(1)(7.133 \times 10^{-4}\ mm)(1000\ mm)}{(.00125\ mm)}$

$x_m = 570.64\ mm$ (farther away)

Commentary:

This student uses the small angle approximation in part (a). In part (b), there is no clear indication that the student realizes that a difference in energy levels is required.

Question 8 (10 points) — Scoring Guidelines

Each part of this question is individually straightforward, but the student is required to use understanding of a number of topics to successfully complete the entire question. The question deals with the production of a magnetic field by a long straight wire, magnetic forces on moving electric charges, and the electrostatic force on an electric charge. An important part of a complete solution to the problem also requires the student to understand the relationships between the directions of the various forces and fields.

	Distribution of points
(a) 2 points	
For indicating that the magnetic field is along the z axis, or indicating that the right-hand rule applies	1 point
For indicating the correct direction along the z axis (e.g. $-z$, or into the page)	1 point
(b) 2 points	
For indicating that the magnetic force is along the y axis, or indicating that the right-hand rule applies	1 point
For indicating the correct direction along the y axis (e.g. $-y$, down, toward wire)	1 point
Full credit was awarded for an answer that was consistent with the answer to part (a) according to the right-hand rule	
(c) 3 points	
For using the appropriate equation for the magnetic force $F = qvB \sin\theta$	1 point
For using the appropriate equation for the magnetic field $B = \frac{\mu_0 I}{2\pi r}$ or $\frac{2k'I}{r}$	1 point
For the correct answer (which must have the substitutions $\sin\theta = 1$ and $r = d$) $F = \frac{q v_0 \mu_0 I}{2\pi d}$ or $\frac{2k' q v_0 I}{d}$	1 point

Two points were awarded if one of the equations for F or B was incorrect, but the above substitutions were made.

Distribution of points

Question 8 (continued)

(d)

i. 1 point

For indicating that the electric field is in the $+y$-direction (e.g. up, opposite the magnetic force) — 1 point

Full credit was awarded for an answer that was consistent with the answer to part (b)

ii. 2 points

For any indication that the electric and magnetic forces are equal and opposite — 1 point

$$F_E = F_B$$
$$qE = qvB$$
$$qE = \frac{qv_0\mu_0 I}{2\pi d}$$

For the correct answer — 1 point

$$E = \frac{v_0\mu_0 I}{2\pi d}$$

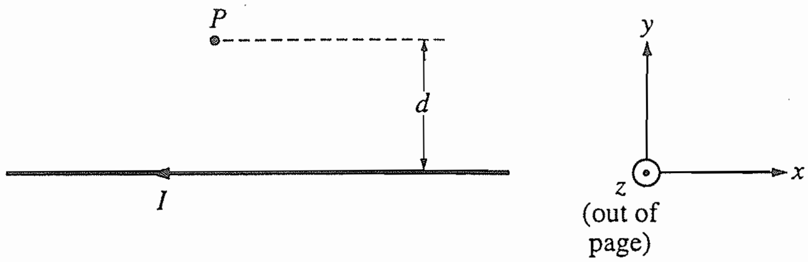


Figure 1

8. (10 points)
The long, straight wire shown in Figure 1 above is in the plane of the page and carries a current I. Point P is also in the plane of the page and is a perpendicular distance d from the wire. Gravitational effects are negligible.

(a) With reference to the coordinate system in Figure 1, what is the direction of the magnetic field at point P due to the current in the wire?

Due to the current in the wire, the magnetic field at point P will be pointing into the paper. (Right-hand Rule)

A particle of mass m and positive charge q is initially moving parallel to the wire with a speed v_0 when it is at point P, as shown in Figure 2 below.

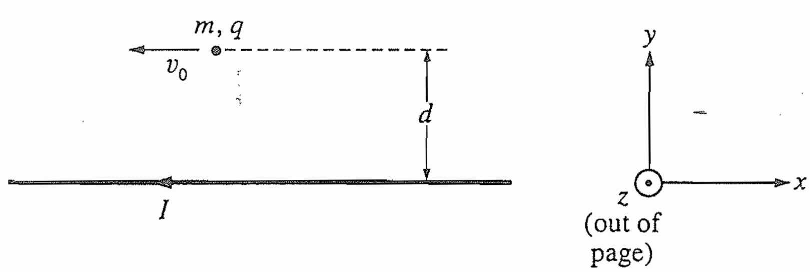


Figure 2

(b) With reference to the coordinate system in Figure 2, what is the direction of the magnetic force acting on the particle at point P ?

The magnetice force acting on the particle at point P is towarding down to the botton of the page. (Right-hand Rule)

(c) Determine the magnitude of the magnetic force acting on the particle at point P in terms of the given quantities and fundamental constants.

The magnetic force acting on the particle at point P is given by $F_B = qVB\sin\theta$

and since, the particle has charge q and speed V_0, the θ between magnetic field and its v direction is $90°$.

$$\therefore F_B = qV_0B.$$

$$\text{and } B = \frac{\mu_0 I}{2\pi r} = \frac{4\pi \times 10^{-7} I}{2\pi d} = 2\times10^{-7}\frac{I}{d}.$$

$$\therefore F_B = qV_0B = qV_0\left(2\times10^{-7}\frac{I}{d}\right)$$

$$= \frac{2\times10^{-7} qV_0 I}{d}$$

(d) An electric field is applied that causes the net force on the particle to be zero at point P.

i. With reference to the coordinate system in Figure 2, what is the direction of the electric field at point P that could accomplish this?

The direction of electric field should be towarding up to the top of the page, so the magnetic force and electric force would cancel out, and net force become zero.

ii. Determine the magnitude of the electric field in terms of the given quantities and fundamental constants.

Since $|F_e| = |F_B|$

$$\therefore F_e = \frac{2\times10^{-7} qV_0 I}{d}$$

and since $E = \frac{F}{q}$, and charge of the particle is q.

$$\therefore E = \frac{\;\frac{2\times10^{-7} qV_0 I}{d}\;}{q}$$

$$= \frac{2\times10^{-7} qV_0 I}{d \cdot q}$$

$$= \frac{2\times10^{-7} V_0 I}{d}.$$

$\therefore$ The magnitude of the electric field is $\frac{2\times10^{-7} V_0 I}{d}$.

Commentary:

This is an exemplary solution. Note that the student substituted the values of the constants in the answers to parts (c) and (d)ii.

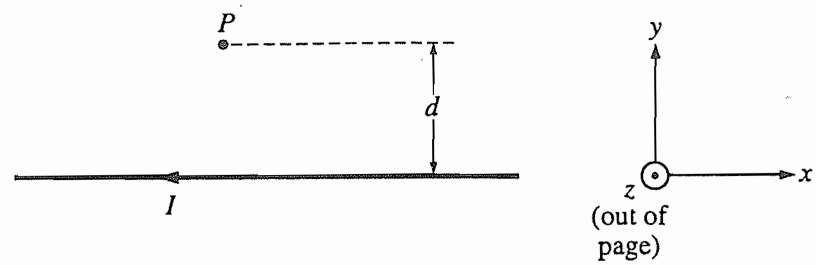


Figure 1

8. (10 points)
The long, straight wire shown in Figure 1 above is in the plane of the page and carries a current I. Point P is also in the plane of the page and is a perpendicular distance d from the wire. Gravitational effects are negligible.

(a) With reference to the coordinate system in Figure 1, what is the direction of the magnetic field at point P due to the current in the wire?

Using Right-Hand Rule
The magnetic field at P is
directed along z axis into page.

A particle of mass m and positive charge q is initially moving parallel to the wire with a speed v_0 when it is at point P, as shown in Figure 2 below.

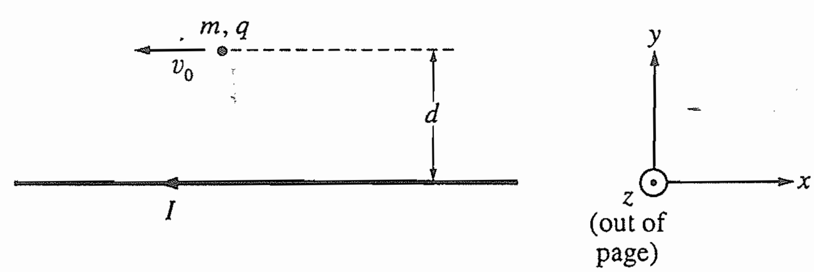


Figure 2

(b) With reference to the coordinate system in Figure 2, what is the direction of the magnetic force acting on the particle at point P ?

Using Right-Hand Rule,
the magnetic force is along
y-axis, downward.

(c) Determine the magnitude of the magnetic force acting on the particle at point P in terms of the given quantities and fundamental constants.

$F = qvB\sin\theta$

$\theta = 90°$

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

$F = \frac{qv\mu_0 I}{2\pi d}$

(d) An electric field is applied that causes the net force on the particle to be zero at point P.

i. With reference to the coordinate system in Figure 2, what is the direction of the electric field at point P that could accomplish this?

The electric field is directed ~~and~~ along y-axis, upward.

ii. Determine the magnitude of the electric field in terms of the given quantities and fundamental constants.

$F = \frac{kq}{r}$

$F = \frac{kq}{d}$

Commentary:

This student's responses are correct until the last part, where the student tries to start with an expression for electric force that is incorrect.

Chapter IV The 1998 AP Physics C Examination

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

Exam Content and Format

The Physics C Examination consists of two parts, one covering mechanics and the other covering electricity & magnetism, at the level of an introductory survey course that uses calculus. Each part is 90 minutes long and is divided equally in time between a 35-question multiple-choice section and a three-question free-response section. For each part, the two sections are weighted equally, and a single grade is reported. A student is expected to spend about 15 minutes answering each free-response question.

The percentages to be devoted to each major category are as follows. (A more detailed outline can be found in the Advanced Placement Course Description in Physics; see the back of this book for ordering information.)

Content Area	Percentage Goals for Physics C exam
I. Newtonian Mechanics	50%
A. Kinematics	9%
B. Newton's laws of motion	10%
C. Work, energy, power	7%
D. Systems of particles, liner momentum	6%
E. Circular motion and rotation	9%
F. Oscillations and gravitation	9%
II. Electricity and Magnetism	50%
A. Electrostatics	15%
B. Conductors, capacitors, dielectrics	7%
C. Electric circuits	10%
D. Magnetostatics	10%
E. Electromagnetism	8%

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 sections to facilitate the sketching of graphs or diagrams that might be required. Calculators are not permitted on the multiple-choice sections. They are allowed on the free-response sections. 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 146-148) provided with each examination for students to use when taking the free-response sections. These equations are not permitted for the multiple-choice sections. 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

You may wish to create an exam situation for your students that closely resembles a national administration. Pages 9-18 contain the instructions, as printed in the 1998 *Coordinator's Manual*, for administering the AP Physics C Exam, along with those for the AP Physics B Exam. 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." It is just that: a packet of ten of the 1998 AP Physics C Exam, and blank answer sheets. For ordering information, see the back of this book.

PHYSICS C

You may take the entire C Exam or Mechanics only or Electricity and Magnetism only as follows:

	Entire C Exam Both Mech. & Elect. and Mag.	Mechanics only	Electricity and Magnetism only
First 45 min.	Sec. I, Mech. 35 questions this booklet, pp. 4-14	Sec. I, Mech. 35 questions this booklet, pp. 4-14	Sec. I, Elect. and Mag. 35 questions this booklet, pp. 16-26
2-minute interval		Survey Questions 7 questions (101-107) this booklet, pp. 28-29	Survey Questions 7 questions (101-107) this booklet, pp. 28-29
Second 45 min.	Sec. I, Elect. and Mag. 35 questions this booklet, pp. 16-26	Sec. II, Mech. 3 questions pink booklet, pp. 4-15	Sec. II, Elect. and Mag. 3 questions pink booklet, pp. 16-25
2-minute interval	Survey Questions 7 questions (101-107) this booklet, pp. 28-29		
Third 45 min.	Sec. II, Mech. 3 questions pink booklet, pp. 4-15		
Fourth 45 min.	Sec. II, Elec. and Mag. 3 questions pink booklet, pp. 16-25		

Separate grades are reported for Mechanics and for Electricity and Magnetism. Each section of each examination is 50 percent of the total grade; each question in a section has equal weight. Rulers or straightedges may be used in all parts of this examination. However, calculators may only be used in the two parts of Section II, NOT in Section I. Calculators may not be shared. A table of information that may be helpful is found on page 2 of this booklet.

This examination contains a total of 70 multiple-choice questions. If you are taking

- ***Mechanics only*, please be careful to use the answer sheet ovals numbered 1-35.**
- ***Electricity and Magnetism only*, please be careful to use the answer sheet ovals numbered 36-70.**
- ***the entire examination* (Mechanics *and* Electricity and Magnetism), please be careful to use the answer sheet ovals numbered 1-70 on your answer sheet.**

Also, please be careful to use the ovals numbered 101-107 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.

TABLE OF INFORMATION FOR 1998

CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\text{u} = 1.66 \times 10^{-27}$ kg
	$= 931\ \text{MeV}/c^2$
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,	$N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$
Universal gas constant,	$R = 8.31\ \text{J}/(\text{mol}\cdot\text{K})$
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,	$h = 6.63 \times 10^{-34}\ \text{J}\cdot\text{s}$
	$= 4.14 \times 10^{-15}\ \text{eV}\cdot\text{s}$
	$hc = 1.99 \times 10^{-25}\ \text{J}\cdot\text{m}$
	$= 1.24 \times 10^{3}\ \text{eV}\cdot\text{nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}\ (\text{T}\cdot\text{m})/\text{A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}\ (\text{T}\cdot\text{m})/\text{A}$
Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg}\cdot\text{s}^2$
Acceleration due to gravity at the Earth's surface,	$g = 9.8\ \text{m/s}^2$
1 atmosphere pressure,	$1\ \text{atm} = 1.0 \times 10^{5}\ \text{N/m}^2$
	$= 1.0 \times 10^{5}$ Pa
1 electron volt,	$1\ \text{eV} = 1.60 \times 10^{-19}$ J
1 angstrom,	$1\ \text{Å} = 1 \times 10^{-10}$ 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	$\sin\theta$	$\cos\theta$	$\tan\theta$
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.

PHYSICS C

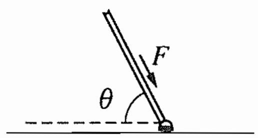
SECTION I, MECHANICS

Time—45 minutes

35 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.



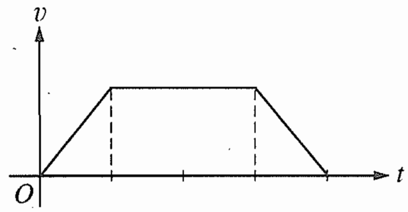
1. A force F is exerted by a broom handle on the head of the broom, which has a mass m. The handle is at an angle θ to the horizontal, as shown above. The work done by the force on the head of the broom as it moves a distance d across a horizontal floor is

   (A) $Fd \sin \theta$
   (B) $Fd \cos \theta$
   (C) $Fm \cos \theta$
   (D) $Fm \tan \theta$
   (E) $Fmd \sin \theta$

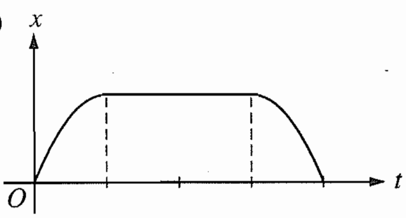
2. The velocity of a projectile at launch has a horizontal component v_h and a vertical component v_v. Air resistance is negligible. When the projectile is at the highest point of its trajectory, which of the following show the vertical and horizontal components of its velocity and the vertical component of its acceleration?

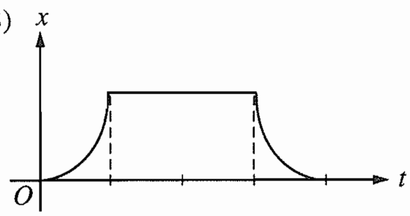
	Vertical Velocity	Horizontal Velocity	Vertical Acceleration
(A)	v_v	v_h	0
(B)	v_v	0	0
(C)	0	v_h	0
(D)	0	0	g
(E)	0	v_h	g

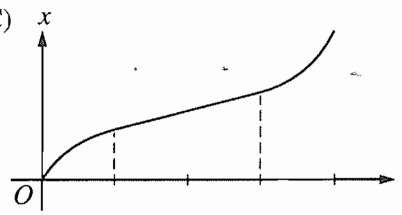
GO ON TO THE NEXT PAGE

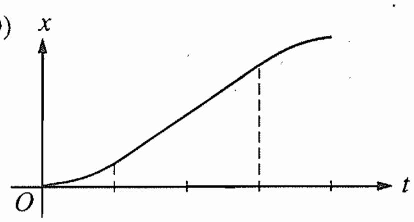


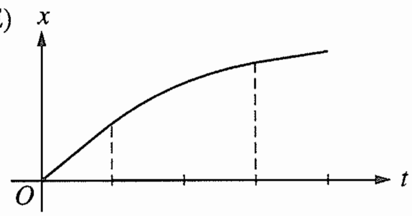
3. The graph above shows the velocity v as a function of time t for an object moving in a straight line. Which of the following graphs shows the corresponding displacement x as a function of time t for the same time interval?

(A) 

(B) 

(C) 

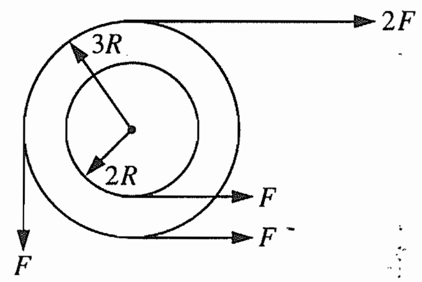
(D) 

(E) 

GO ON TO THE NEXT PAGE

4. The position of a toy locomotive moving on a straight track along the x-axis is given by the equation $x = t^3 - 6t^2 + 9t$, where x is in meters and t is in seconds. The net force on the locomotive is equal to zero when t is equal to

   (A) zero
   (B) 2 s
   (C) 3 s
   (D) 4 s
   (E) 5 s



5. A system of two wheels fixed to each other is free to rotate about a frictionless axis through the common center of the wheels and perpendicular to the page. Four forces are exerted tangentially to the rims of the wheels, as shown above. The magnitude of the net torque on the system about the axis is

   (A) zero
   (B) FR
   (C) $2FR$
   (D) $5FR$
   (E) $14FR$

6. A wheel of mass M and radius R rolls on a level surface without slipping. If the angular velocity of the wheel is ω, what is its linear momentum?

   (A) $M\omega R$
   (B) $M\omega^2 R$
   (C) $M\omega R^2$
   (D) $\dfrac{M\omega^2 R^2}{2}$
   (E) Zero

GO ON TO THE NEXT PAGE

Questions 7-8 refer to a ball that is tossed straight up from the surface of a small, spherical asteroid with no atmosphere. The ball rises to a height equal to the asteroid's radius and then falls straight down toward the surface of the asteroid.

7. What forces, if any, act on the ball while it is on the way up?

(A) Only a decreasing gravitational force that acts downward
(B) Only an increasing gravitational force that acts downward
(C) Only a constant gravitational force that acts downward
(D) Both a constant gravitational force that acts downward and a decreasing force that acts upward
(E) No forces act on the ball.

8. The acceleration of the ball at the top of its path is

(A) at its maximum value for the ball's flight
(B) equal to the acceleration at the surface of the asteroid
(C) equal to one-half the acceleration at the surface of the asteroid
(D) equal to one-fourth the acceleration at the surface of the asteroid
(E) zero

---

9. The equation of motion of a simple harmonic oscillator is $\frac{d^2x}{dt^2} = -9x$, where x is displacement and t is time. The period of oscillation is

(A) 6π
(B) $\frac{9}{2\pi}$
(C) $\frac{3}{2\pi}$
(D) $\frac{2\pi}{3}$
(E) $\frac{2\pi}{9}$

10. A pendulum with a period of 1 s on Earth, where the acceleration due to gravity is g, is taken to another planet, where its period is 2 s. The acceleration due to gravity on the other planet is most nearly

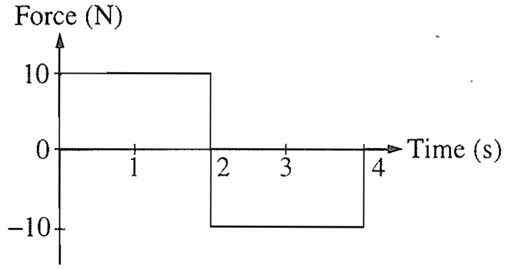
(A) $g/4$
(B) $g/2$
(C) g
(D) $2g$
(E) $4g$

11. A satellite of mass M moves in a circular orbit of radius R with constant speed v. True statements about this satellite include which of the following?

I. Its angular speed is v/R.
II. Its tangential acceleration is zero.
III. The magnitude of its centripetal acceleration is constant.

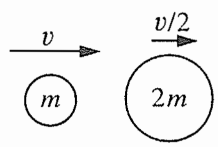
(A) I only
(B) II only
(C) I and III only
(D) II and III only
(E) I, II, and III

GO ON TO THE NEXT PAGE



12. The graph above shows the force on an object of mass M as a function of time. For the time interval 0 to 4 s, the total change in the momentum of the object is

(A) 40 kg•m/s
(B) 20 kg•m/s
(C) 0 kg•m/s
(D) −20 kg•m/s
(E) indeterminable unless the mass M of the object is known



Top View

13. As shown in the top view above, a disc of mass m is moving horizontally to the right with speed v on a table with negligible friction when it collides with a second disc of mass $2m$. The second disc is moving horizontally to the right with speed $\frac{v}{2}$ at the moment of impact. The two discs stick together upon impact. The speed of the composite body immediately after the collision is

(A) $\frac{v}{3}$

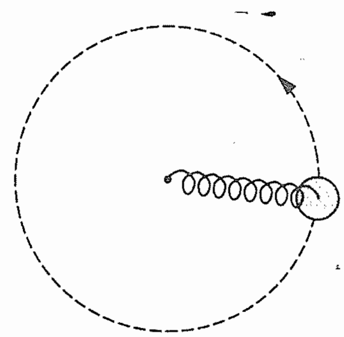
(B) $\frac{v}{2}$

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

(D) $\frac{3v}{2}$

(E) $2v$

Questions 14-15



Top View

A spring has a force constant of 100 N/m and an unstretched length of 0.07 m. One end is attached to a post that is free to rotate in the center of a smooth table, as shown in the top view above. The other end is attached to a 1 kg disc moving in uniform circular motion on the table, which stretches the spring by 0.03 m. Friction is negligible.

14. What is the centripetal force on the disc?

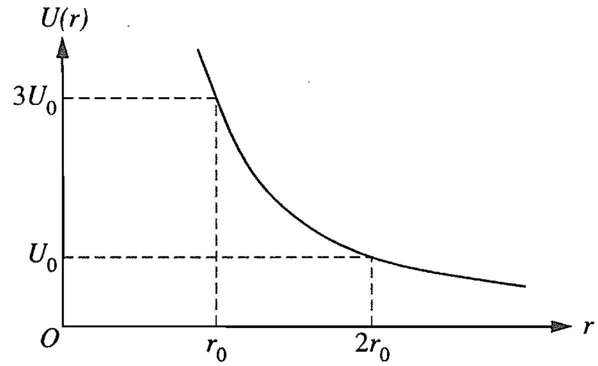
(A) 0.3 N
(B) 3 N
(C) 10 N
(D) 300 N
(E) 1,000 N

15. What is the work done on the disc by the spring during one full circle?

(A) 0 J
(B) 94 J
(C) 186 J
(D) 314 J
(E) 628 J

GO ON TO THE NEXT PAGE

Questions 16-17 refer to the following graph, which represents a hypothetical potential energy curve for a particle of mass m.



16. If the particle is released from rest at position r_0, its speed at position $2r_0$ is most nearly

(A) $\sqrt{\dfrac{8U_0}{m}}$

(B) $\sqrt{\dfrac{6U_0}{m}}$

(C) $\sqrt{\dfrac{4U_0}{m}}$

(D) $\sqrt{\dfrac{2U_0}{m}}$

(E) $\sqrt{\dfrac{U_0}{m}}$

17. If the potential energy function is given by $U(r) = br^{-3/2} + c$, where b and c are constants, which of the following is an expression for the force on the particle?

(A) $\dfrac{3b}{2} r^{-5/2}$

(B) $\dfrac{3b}{2} r^{-1/2}$

(C) $\dfrac{3}{2} r^{-1/2}$

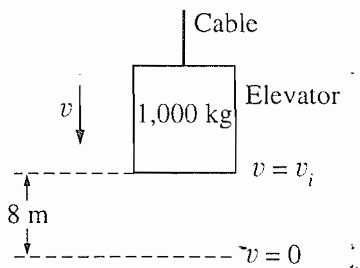
(D) $2br^{-1/2} + cr$

(E) $\dfrac{2b}{5} r^{-5/2} + cr$

GO ON TO THE NEXT PAGE

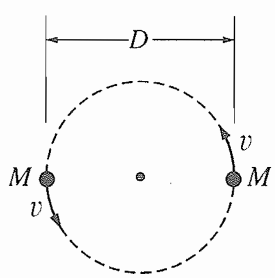
18. A frictionless pendulum of length 3 m swings with an amplitude of 10°. At its maximum displacement, the potential energy of the pendulum is 10 J. What is the kinetic energy of the pendulum when its potential energy is 5 J ?

(A) 3.3 J
(B) 5 J
(C) 6.7 J
(D) 10 J
(E) 15 J



19. A descending elevator of mass 1,000 kg is uniformly decelerated to rest over a distance of 8 m by a cable in which the tension is 11,000 N. The speed v_i of the elevator at the beginning of the 8 m descent is most nearly

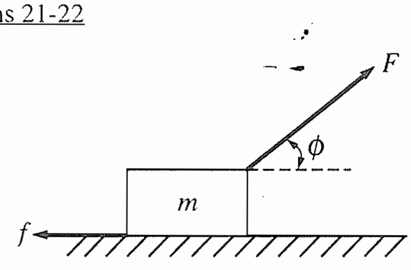
(A) 4 m/s
(B) 10 m/s
(C) 13 m/s
(D) 16 m/s
(E) 21 m/s



20. Two identical stars, a fixed distance D apart, revolve in a circle about their mutual center of mass, as shown above. Each star has mass M and speed v. G is the universal gravitational constant. Which of the following is a correct relationship among these quantities?

(A) $v^2 = GM/D$
(B) $v^2 = GM/2D$
(C) $v^2 = GM/D^2$
(D) $v^2 = MGD$
(E) $v^2 = 2GM^2/D$

Questions 21-22



A block of mass m is accelerated across a rough surface by a force of magnitude F that is exerted at an angle ϕ with the horizontal, as shown above. The frictional force on the block exerted by the surface has magnitude f.

21. What is the acceleration of the block?

(A) $\dfrac{F}{m}$

(B) $\dfrac{F\cos\phi}{m}$

(C) $\dfrac{F - f}{m}$

(D) $\dfrac{F\cos\phi - f}{m}$

(E) $\dfrac{F\sin\phi - mg}{m}$

22. What is the coefficient of friction between the block and the surface?

(A) $\dfrac{f}{mg}$

(B) $\dfrac{mg}{f}$

(C) $\dfrac{mg - F\cos\phi}{f}$

(D) $\dfrac{f}{mg - F\cos\phi}$

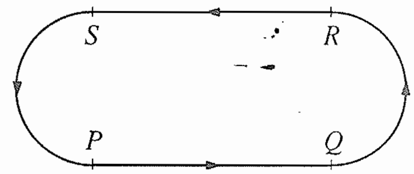
(E) $\dfrac{f}{mg - F\sin\phi}$

GO ON TO THE NEXT PAGE

23. This question was not counted when the exam was scored.

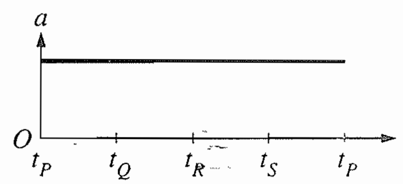
24. Two people are initially standing still on frictionless ice. They push on each other so that one person, of mass 120 kg, moves to the left at 2 m/s, while the other person, of mass 80 kg, moves to the right at 3 m/s. What is the velocity of their center of mass?

(A) Zero
(B) 0.5 m/s to the left
(C) 1 m/s to the right
(D) 2.4 m/s to the left
(E) 2.5 m/s to the right

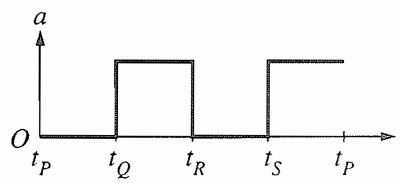


25. A figure of a dancer on a music box moves counterclockwise at constant speed around the path shown above. The path is such that the lengths of its segments, PQ, QR, RS, and SP, are equal. Arcs QR and SP are semicircles. Which of the following best represents the magnitude of the dancer's acceleration as a function of time t during one trip around the path, beginning at point P ?

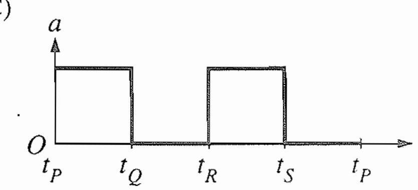
(A)



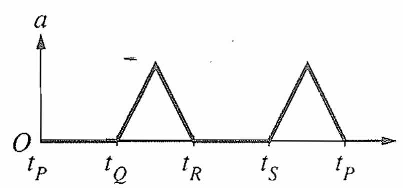
(B)



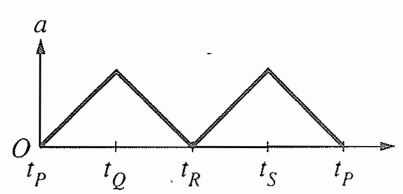
(C)



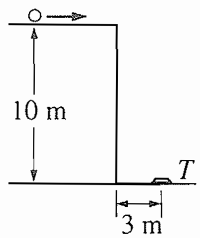
(D)



(E)



GO ON TO THE NEXT PAGE



26. A target T lies flat on the ground 3 m from the side of a building that is 10 m tall, as shown above. A student rolls a ball off the horizontal roof of the building in the direction of the target. Air resistance is negligible. The horizontal speed with which the ball must leave the roof if it is to strike the target is most nearly

(A) $\frac{3}{10}$ m/s

(B) $\sqrt{2}$ m/s

(C) $\frac{3}{\sqrt{2}}$ m/s

(D) 3 m/s

(E) $10\sqrt{\frac{5}{3}}$ m/s

27. To stretch a certain nonlinear spring by an amount x requires a force F given by $F = 40x - 6x^2$, where F is in newtons and x is in meters. What is the change in potential energy when the spring is stretched 2 meters from its equilibrium position?

(A) 16 J
(B) 28 J
(C) 56 J
(D) 64 J
(E) 80 J

28. When a block slides a certain distance down an incline, the work done by gravity is 300 J. What is the work done by gravity if this block slides the same distance up the incline?

(A) 300 J
(B) Zero
(C) –300 J
(D) It cannot be determined without knowing the distance the block slides.
(E) It cannot be determined without knowing the coefficient of friction.

29. A particle moves in the xy-plane with coordinates given by

$$x = A\cos\omega t \text{ and } y = A\sin\omega t,$$

where $A = 1.5$ meters and $\omega = 2.0$ radians per second. What is the magnitude of the particle's acceleration?

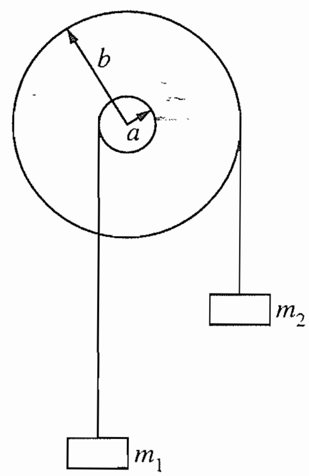
(A) Zero

(B) 1.3 m/s^2

(C) 3.0 m/s^2

(D) 4.5 m/s^2

(E) 6.0 m/s^2



30. For the wheel-and-axle system shown above, which of the following expresses the condition required for the system to be in static equilibrium?

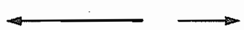
(A) $m_1 = m_2$
(B) $am_1 = bm_2$
(C) $am_2 = bm_1$
(D) $a^2m_1 = b^2m_2$
(E) $b^2m_1 = a^2m_2$

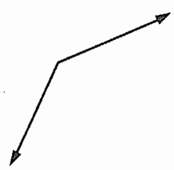
GO ON TO THE NEXT PAGE

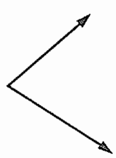
31. An object having an initial momentum that may be represented by the vector above strikes an object that is initially at rest. Which of the following sets of vectors may represent the momenta of the two objects after the collision?

(A)

(B)

(C) 

(D) 

(E) 

Questions 32-33

A wheel with rotational inertia I is mounted on a fixed, frictionless axle. The angular speed ω of the wheel is increased from zero to ω_f in a time interval T.

32. What is the average net torque on the wheel during this time interval?

(A) $\dfrac{\omega_f}{T}$

(B) $\dfrac{\omega_f}{T^2}$

(C) $\dfrac{I\omega_f^2}{T}$

(D) $\dfrac{I\omega_f}{T^2}$

(E) $\dfrac{I\omega_f}{T}$

33. What is the average power input to the wheel during this time interval?

(A) $\dfrac{I\omega_f}{2T}$

(B) $\dfrac{I\omega_f^2}{2T}$

(C) $\dfrac{I\omega_f^2}{2T^2}$

(D) $\dfrac{I^2\omega_f}{2T^2}$

(E) $\dfrac{I^2\omega_f^2}{2T^2}$

GO ON TO THE NEXT PAGE

34. An object is released from rest at time $t = 0$ and falls through the air, which exerts a resistive force such that the acceleration a of the object is given by $a = g - bv$, where v is the object's speed and b is a constant. If limiting cases for large and small values of t are considered, which of the following is a possible expression for the speed of the object as an explicit function of time?

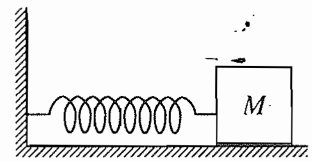
(A) $v = g\left(1 - e^{-bt}\right)/b$

(B) $v = \left(ge^{bt}\right)/b$

(C) $v = gt - bt^2$

(D) $v = (g + a)t/b$

(E) $v = v_0 + gt,\ v_0 \neq 0$



35. An ideal massless spring is fixed to the wall at one end, as shown above. A block of mass M attached to the other end of the spring oscillates with amplitude A on a frictionless, horizontal surface. The maximum speed of the block is v_m. The force constant of the spring is

(A) $\dfrac{Mg}{A}$

(B) $\dfrac{Mgv_m}{2A}$

(C) $\dfrac{Mv_m^2}{2A}$

(D) $\dfrac{Mv_m^2}{A^2}$

(E) $\dfrac{Mv_m^2}{2A^2}$

STOP

END OF SECTION I, MECHANICS

IF YOU FINISH BEFORE TIME IS CALLED, YOU MAY CHECK YOUR WORK ON SECTION I, MECHANICS, ONLY.
DO NOT TURN TO ANY OTHER TEST MATERIALS.

PHYSICS C

SECTION I, ELECTRICITY AND MAGNETISM

Time—45 minutes

35 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.

36. A resistor R and a capacitor C are connected in series to a battery of terminal voltage V_0. Which of the following equations relating the current I in the circuit and the charge Q on the capacitor describes this circuit?

(A) $V_0 + QC - I^2R = 0$

(B) $V_0 - \frac{Q}{C} - IR = 0$

(C) $V_0^2 - \frac{1}{2}\frac{Q^2}{C} - I^2R = 0$

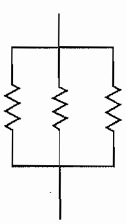
(D) $V_0 - C\frac{dQ}{dt} - I^2R = 0$

(E) $\frac{Q}{C} - IR = 0$

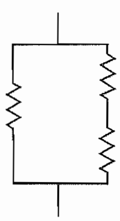
37. Which of the following combinations of 4 Ω resistors would dissipate 24 W when connected to a 12 V battery?

(A)

(B)

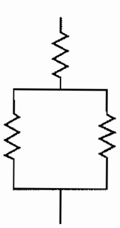


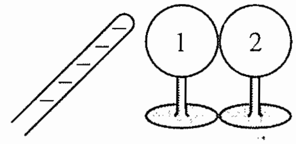
(C)



(D)

(E)



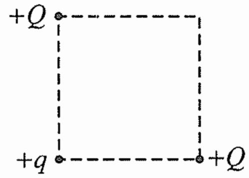


38. Two initially uncharged conductors, 1 and 2, are mounted on insulating stands and are in contact, as shown above. A negatively charged rod is brought near but does not touch them. With the rod held in place, conductor 2 is moved to the right by pushing its stand, so that the conductors are separated. Which of the following is now true of conductor 2 ?

(A) It is uncharged.
(B) It is positively charged.
(C) It is negatively charged.
(D) It is charged, but its sign cannot be predicted.
(E) It is at the same potential that it was before the charged rod was brought near.

GO ON TO THE NEXT PAGE

Questions 39-40



As shown above, two particles, each of charge $+Q$, are fixed at opposite corners of a square that lies in the plane of the page. A positive test charge $+q$ is placed at a third corner.

39. What is the direction of the force on the test charge due to the two other charges?

(A) 

(B)

(C) 

(D) 

(E) 

40. If F is the magnitude of the force on the test charge due to only one of the other charges, what is the magnitude of the net force acting on the test charge due to both of these charges?

(A) Zero

(B) $F/\sqrt{2}$

(C) F

(D) $\sqrt{2}\,F$

(E) $2\,F$

41. Gauss's law provides a convenient way to calculate the electric field outside and near each of the following isolated charged conductors EXCEPT a

(A) large plate
(B) sphere
(C) cube
(D) long, solid rod
(E) long, hollow cylinder

42. A wire of resistance R dissipates power P when a current I passes through it. The wire is replaced by another wire with resistance $3R$. The power dissipated by the new wire when the same current passes through it is

(A) $\frac{P}{9}$

(B) $\frac{P}{3}$

(C) P

(D) $3P$

(E) $6P$

GO ON TO THE NEXT PAGE

Questions 43-44

A narrow beam of protons produces a current of 1.6×10^{-3} A. There are 10^9 protons in each meter along the beam.

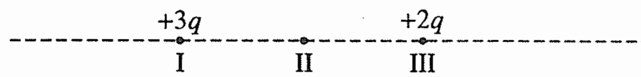
43. Of the following, which is the best estimate of the average speed of the protons in the beam?

(A) 10^{-15} m/s
(B) 10^{-12} m/s
(C) 10^{-7} m/s
(D) 10^{7} m/s
(E) 10^{12} m/s

44. Which of the following describes the lines of magnetic field in the vicinity of the beam due to the beam's current?

(A) Concentric circles around the beam
(B) Parallel to the beam
(C) Radial and toward the beam
(D) Radial and away from the beam
(E) There is no magnetic field.

Questions 45-46 refer to two charges located on the line shown in the figure below, in which the charge at point I is $+3q$ and the charge at point III is $+2q$. Point II is halfway between points I and III.



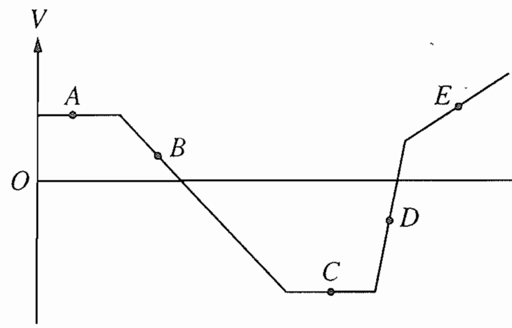
45. Other than at infinity, the electric field strength is zero at a point on the line in which of the following ranges?

(A) To the left of I
(B) Between I and II
(C) Between II and III
(D) To the right of III
(E) None; the field is zero only at infinity.

46. The electric potential is negative at some points on the line in which of the following ranges?

(A) To the left of I
(B) Between I and II
(C) Between II and III
(D) To the right of III
(E) None; this potential is never negative.

GO ON TO THE NEXT PAGE

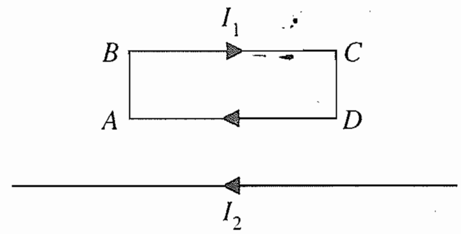


47. The graph above shows the electric potential V in a region of space as a function of position along the x-axis. At which point would a charged particle experience the force of greatest magnitude?

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

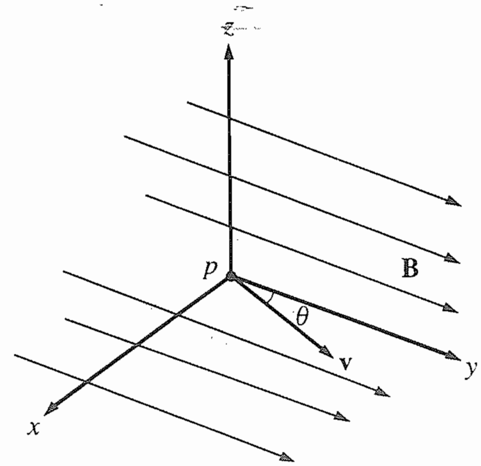
48. The work that must be done by an external agent to move a point charge of 2 mC from the origin to a point 3 m away is 5 J. What is the potential difference between the two points?

(A) 4×10^{-4} V
(B) 10^{-2} V
(C) 2.5×10^{3} V
(D) 2×10^{6} V
(E) 6×10^{6} V



49. A rigid, rectangular wire loop $ABCD$ carrying current I_1 lies in the plane of the page above a very long wire carrying current I_2, as shown above. The net force on the loop is

(A) toward the wire
(B) away from the wire
(C) toward the left
(D) toward the right
(E) zero



50. A uniform magnetic field **B** is parallel to the xy-plane and in the $+y$-direction, as shown above. A proton p initially moves with velocity **v** in the xy-plane at an angle θ to the magnetic field and the y-axis. The proton will subsequently follow what kind of path?

(A) A straight-line path in the direction of **v**
(B) A circular path in the xy-plane
(C) A circular path in the yz-plane
(D) A helical path with its axis parallel to the y-axis
(E) A helical path with its axis parallel to the z-axis

GO ON TO THE NEXT PAGE

51. A parallel-plate capacitor has charge $+Q$ on one plate and charge $-Q$ on the other. The plates, each of area A, are a distance d apart and are separated by a vacuum. A single proton of charge $+e$, released from rest at the surface of the positively charged plate, will arrive at the other plate with kinetic energy proportional to

(A) $\frac{edQ}{A}$

(B) $\frac{Q^2}{eAd}$

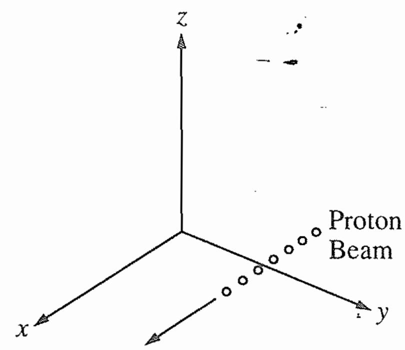
(C) $\frac{AeQ}{d}$

(D) $\frac{Q}{ed}$

(E) $\frac{eQ^2}{Ad}$

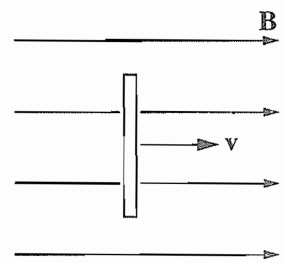
52. In which of the following cases does there exist a nonzero magnetic field that can be conveniently determined by using Ampere's law?

(A) Outside a point charge that is at rest
(B) Inside a stationary cylinder carrying a uniformly distributed charge
(C) Inside a very long current-carrying solenoid
(D) At the center of a current-carrying loop of wire
(E) Outside a square current-carrying loop of wire



53. A beam of protons moves parallel to the x-axis in the positive x-direction, as shown above, through a region of crossed electric and magnetic fields balanced for zero deflection of the beam. If the magnetic field is pointed in the positive y-direction, in what direction must the electric field be pointed?

(A) Positive y-direction
(B) Positive z-direction
(C) Negative x-direction
(D) Negative y-direction
(E) Negative z-direction



54. A vertical length of copper wire moves to the right with a steady velocity **v** in the direction of a constant horizontal magnetic field **B**, as shown above. Which of the following describes the induced charges on the ends of the wire?

	Top End	Bottom End
(A)	Positive	Negative
(B)	Negative	Positive
(C)	Negative	Zero
(D)	Zero	Negative
(E)	Zero	Zero

GO ON TO THE NEXT PAGE

55. Suppose that an electron (charge $-e$) could orbit a proton (charge $+e$) in a circular orbit of constant radius R. Assuming that the proton is stationary and only electrostatic forces act on the particles, which of the following represents the kinetic energy of the two-particle system?

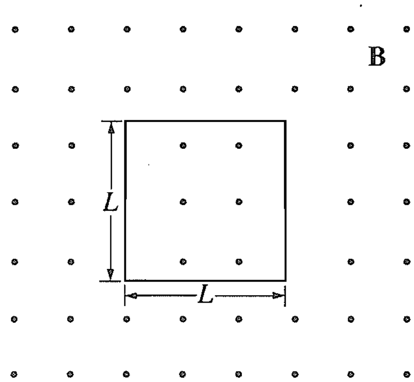
(A) $\frac{1}{4\pi\epsilon_0}\frac{e}{R}$

(B) $\frac{1}{8\pi\epsilon_0}\frac{e^2}{R}$

(C) $-\frac{1}{8\pi\epsilon_0}\frac{e^2}{R}$

(D) $\frac{1}{4\pi\epsilon_0}\frac{e^2}{R^2}$

(E) $-\frac{1}{4\pi\epsilon_0}\frac{e^2}{R^2}$



56. A square wire loop with side L and resistance R is held at rest in a uniform magnetic field of magnitude B directed out of the page, as shown above. The field decreases with time t according to the equation $B = a - bt$, where a and b are positive constants. The current I induced in the loop is

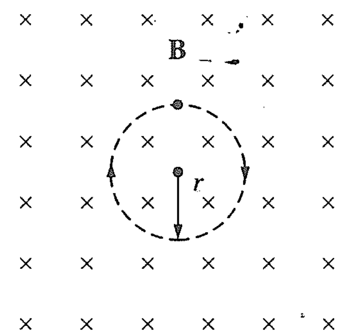
(A) zero

(B) aL^2/R, clockwise

(C) aL^2/R, counterclockwise

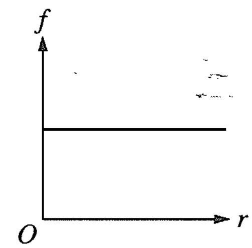
(D) bL^2/R, clockwise

(E) bL^2/R, counterclockwise

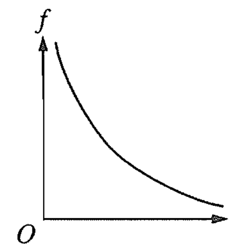


57. A negatively charged particle in a uniform magnetic field $\mathbf{B}$ moves in a circular path of radius r, as shown above. Which of the following graphs best depicts how the frequency of revolution f of the particle depends on the radius r ?

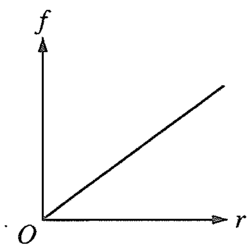
(A)



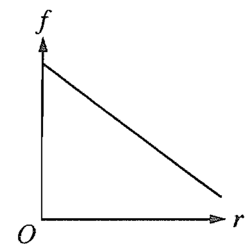
(B)



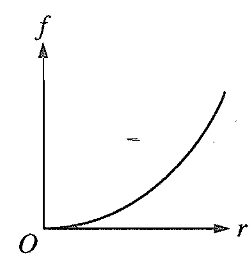
(C)



(D)



(E)



GO ON TO THE NEXT PAGE

58. If the only force acting on an electron is due to a uniform electric field, the electron moves with constant

 (A) acceleration in a direction opposite to that of the field
 (B) acceleration in the direction of the field
 (C) acceleration in a direction perpendicular to that of the field
 (D) speed in a direction opposite to that of the field
 (E) speed in the direction of the field

Questions 59-60

In a region of space, a spherically symmetric electric potential is given as a function of r, the distance from the origin, by the equation $V(r) = kr^2$, where k is a positive constant.

59. What is the magnitude of the electric field at a point a distance r_0 from the origin?

 (A) Zero

 (B) kr_0

 (C) $2kr_0$

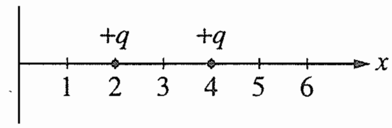
 (D) $kr_0^{\,2}$

 (E) $\frac{2}{3}kr_0^{\,3}$

60. What is the direction of the electric field at a point a distance r_0 from the origin and the direction of the force on an electron placed at this point?

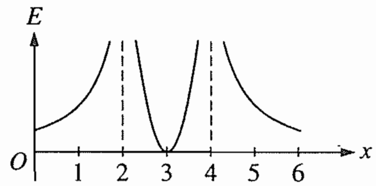
	Electric Field	Force on Electron
(A)	Toward origin	Toward origin
(B)	Toward origin	Away from origin
(C)	Away from origin	Toward origin
(D)	Away from origin	Away from origin
(E)	Undefined, since the field is zero	Undefined, since the force is zero

GO ON TO THE NEXT PAGE

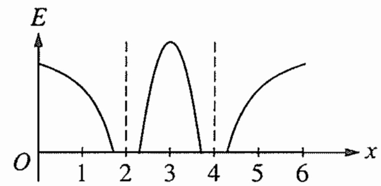


61. Two charged particles, each with a charge of $+q$, are located along the x-axis at $x = 2$ and $x = 4$, as shown above. Which of the following shows the graph of the magnitude of the electric field along the x-axis from the origin to $x = 6$?

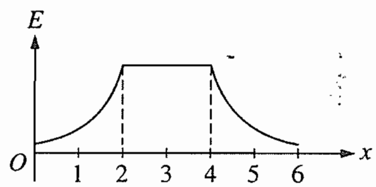
(A)



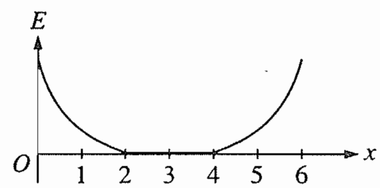
(B)



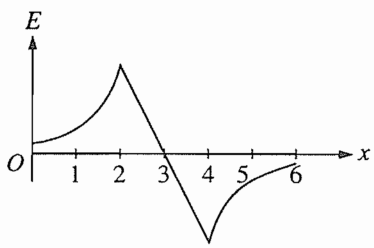
(C)



(D)



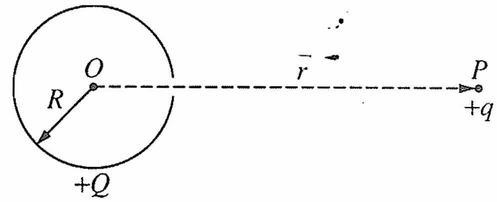
(E)



GO ON TO THE NEXT PAGE

62. A positive electric charge is moved at a constant speed between two locations in an electric field, with no work done by or against the field at any time during the motion. This situation can occur only if the

(A) charge is moved in the direction of the field
(B) charge is moved opposite to the direction of the field
(C) charge is moved perpendicular to an equipotential line
(D) charge is moved along an equipotential line
(E) electric field is uniform



63. The nonconducting hollow sphere of radius R shown above carries a large charge $+Q$, which is uniformly distributed on its surface. There is a small hole in the sphere. A small charge $+q$ is initially located at point P, a distance r from the center of the sphere. If $k = 1/4\pi\epsilon_0$, what is the work that must be done by an external agent in moving the charge $+q$ from P through the hole to the center O of the sphere?

(A) Zero

(B) $\dfrac{kqQ}{r}$

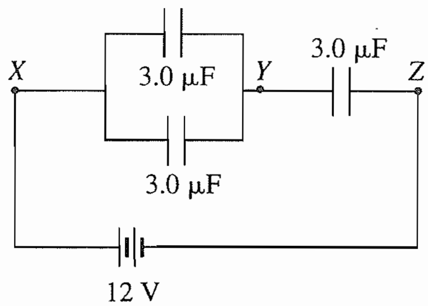
(C) $\dfrac{kqQ}{R}$

(D) $\dfrac{kq(Q-q)}{r}$

(E) $kqQ\left(\dfrac{1}{R} - \dfrac{1}{r}\right)$

GO ON TO THE NEXT PAGE

Questions 64-65



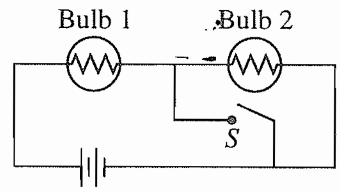
Three identical capacitors, each of capacitance 3.0 μF, are connected in a circuit with a 12 V battery as shown above.

64. The equivalent capacitance between points X and Z is

(A) 1.0 μF
(B) 2.0 μF
(C) 4.5 μF
(D) 6.0 μF
(E) 9.0 μF

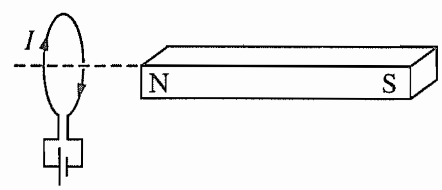
65. The potential difference between points Y and Z is

(A) zero
(B) 3 V
(C) 4 V
(D) 8 V
(E) 9 V



66. The circuit in the figure above contains two identical lightbulbs in series with a battery. At first both bulbs glow with equal brightness. When switch S is closed, which of the following occurs to the bulbs?

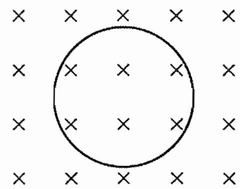
	Bulb 1	Bulb 2
(A)	Goes out	Gets brighter
(B)	Gets brighter	Goes out
(C)	Gets brighter	Gets slightly dimmer
(D)	Gets slightly dimmer	Gets brighter
(E)	Nothing	Goes out



67. A bar magnet and a wire loop carrying current I are arranged as shown above. In which direction, if any, is the force on the current loop due to the magnet?

(A) Toward the magnet
(B) Away from the magnet
(C) Toward the top of the page
(D) Toward the bottom of the page
(E) There is no force on the current loop.

GO ON TO THE NEXT PAGE



68. A wire loop of area A is placed in a time-varying but spatially uniform magnetic field that is perpendicular to the plane of the loop, as shown above. The induced emf in the loop is given by $\mathcal{E} = bAt^{1/2}$, where b is a constant. The time-varying magnetic field could be given by

    (A) $\frac{1}{2}bAt^{-1/2}$

    (B) $\frac{1}{2}bt^{-1/2}$

    (C) $\frac{1}{2}bt^{1/2}$

    (D) $\frac{2}{3}bAt^{3/2}$

    (E) $\frac{2}{3}bt^{3/2}$

Questions 69-70

A capacitor is constructed of two identical conducting plates parallel to each other and separated by a distance d. The capacitor is charged to a potential difference of V_0 by a battery, which is then disconnected.

69. If any edge effects are negligible, what is the magnitude of the electric field between the plates?

    (A) $V_0 d$

    (B) V_0/d

    (C) d/V_0

    (D) V_0/d^2

    (E) V_0^2/d

70. A sheet of insulating plastic material is inserted between the plates without otherwise disturbing the system. What effect does this have on the capacitance?

    (A) It causes the capacitance to increase.
    (B) It causes the capacitance to decrease.
    (C) None; the capacitance does not change.
    (D) Nothing can be said about the effect without knowing the dielectric constant of the plastic.
    (E) Nothing can be said about the effect without knowing the thickness of the sheet.

STOP

END OF SECTION I, ELECTRICITY AND MAGNETISM

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.

PHYSICS C

SECTION II

Free-Response Questions

Mechanics	45 minutes	3 required questions of equal weight on pages 4-15
Electricity and Magnetism	45 minutes	3 required questions of equal weight on pages 16-25

Section II is 50 percent of the total grade for each of the two examinations.

Mark one of the three boxes below to indicate which questions you are answering.

- ☐ Mechanics only
- ☐ Electricity and Magnetism only
- ☐ Both Mechanics and Electricity and Magnetism

General Instructions

When you are told to begin, carefully tear out the green insert and start work. The questions in the green insert are duplicates of those in this booklet, except that in this booklet space has been left after each part of each question for you to write your answers. The green insert may be used for reference only as you answer the free-response questions. NO CREDIT WILL BE GIVEN FOR ANYTHING WRITTEN IN THE GREEN INSERT.

A table of information and lists of equations that may be helpful are on pages 1-3 of the green insert. Show your work and write your answers to each question in the pink booklet only. Be sure to write CLEARLY and LEGIBLY. Credit for your answers depends on your demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should show your work for each part in the space provided after that part. If you need more space, be sure to indicate clearly where you continue your work. Credit will NOT be awarded for work that is not clearly designated as the solution to a specific part of a question. Credit for your work also depends on the quality of your solutions and explanations, so you should SHOW YOUR WORK. If you make an error, you may save time by crossing it out rather than trying to erase it. Crossed-out work will not be graded. You may lose credit for incorrect work that is not crossed out.

The College Board
Advanced Placement Examination
PHYSICS C
SECTION II

TABLE OF INFORMATION FOR 1998

CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\,u = 1.66 \times 10^{-27}$ 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

Angle	Sin	Cos	Tan
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.

This insert may be used for reference and/or scratchwork as you answer the free-response questions, but be sure to show all your work and your answers in the pink booklet. No credit will be given for work shown on this green insert.

ADVANCED PLACEMENT PHYSICS C EQUATIONS FOR 1998

MECHANICS

$v = v_0 + at$

$s = s_0 + v_0 t + \frac{1}{2} at^2$

$v^2 = v_0^2 + 2a(s - s_0)$

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

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

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

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

$F_{fric} \le \mu N$

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

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

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

$\Delta U_g = mgh$

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

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

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

$I = \int r^2 dm = \Sigma m r^2$

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

$v = r\omega$

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

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

$\omega = \omega_0 + \alpha t$

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

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

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

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

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

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

$F_G = -\frac{G m_1 m_2}{r^2}$

$U_G = -\frac{G m_1 m_2}{r}$

a = acceleration
F = force
f = frequency
h = height
I = rotational inertia
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
L = angular momentum
m = mass
N = normal force
P = power
p = momentum
r = distance
s = displacement
T = period
t = time
U = potential energy
v = velocity or speed
W = work
x = displacement
μ = coefficient of friction
θ = angle
τ = torque
ω = angular speed
α = angular acceleration

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$

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

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

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

$V = \frac{1}{4\pi\epsilon_0} \sum \frac{q}{r}$

$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$

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

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

$C_p = \sum_i C_i$

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

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

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

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

$V = IR$

$R_s = \sum_i R_i$

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

$P = IV$

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

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

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

$B_s = \mu_0 n I$

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

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

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

$U_L = \frac{1}{2} L I^2$

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

ADVANCED PLACEMENT PHYSICS C EQUATIONS FOR 1998

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

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

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

Parallelepiped
$V = \ell wh$

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

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

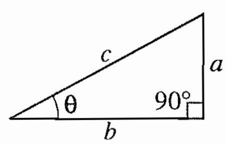
Right Triangle
$a^2 + b^2 = c^2$

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

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

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

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



CALCULUS

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

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

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

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

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

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

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

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

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

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

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

PHYSICS C

SECTION II, MECHANICS

Time—45 minutes

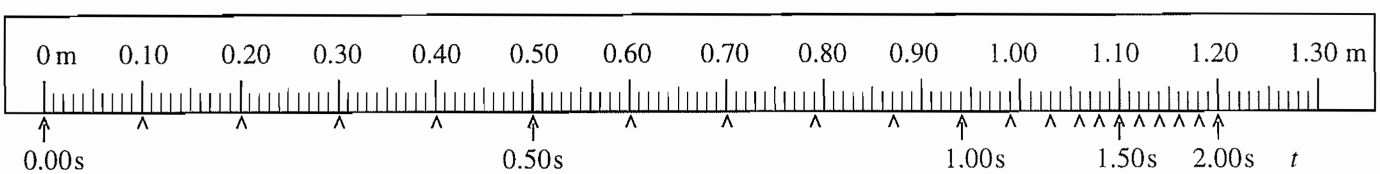
3 Questions

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

Air Track

Mech. 1. Two gliders move freely on an air track with negligible friction, as shown above. Glider A has a mass of 0.90 kg and glider B has a mass of 0.60 kg. Initially, glider A moves toward glider B, which is at rest. A spring of negligible mass is attached to the right side of glider A. Strobe photography is used to record successive positions of glider A at 0.10 s intervals over a total time of 2.00 s, during which time it collides with glider B.

The following diagram represents the data for the motion of glider A. Positions of glider A at the end of each 0.10 s interval are indicated by the symbol ∧ against a metric ruler. The total elapsed time t after each 0.50 s is also indicated.



(a) Determine the average speed of glider A for the following time intervals.

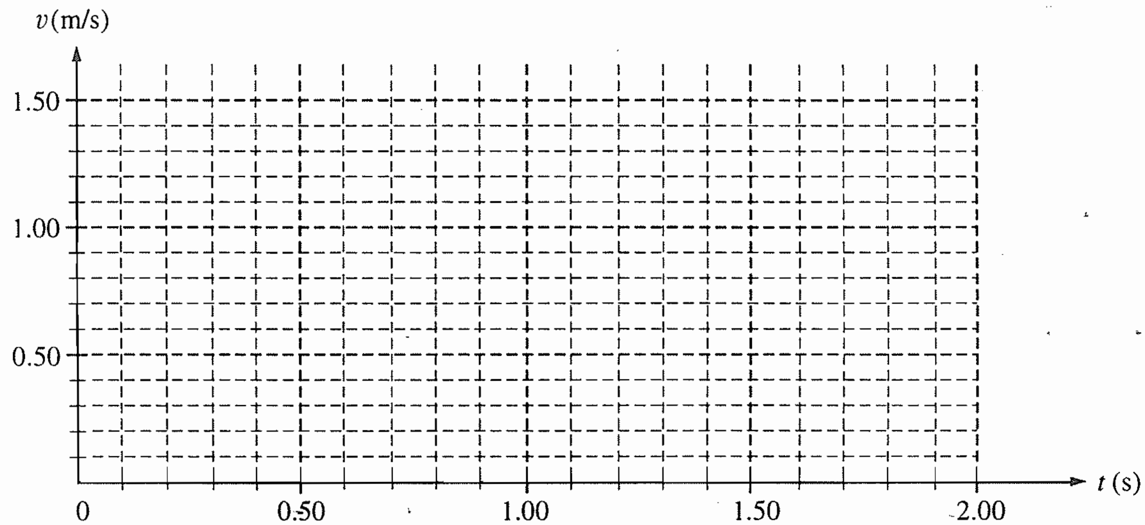
i. 0.10 s to 0.30 s

ii. 0.90 s to 1.10 s

iii. 1.70 s to 1.90 s

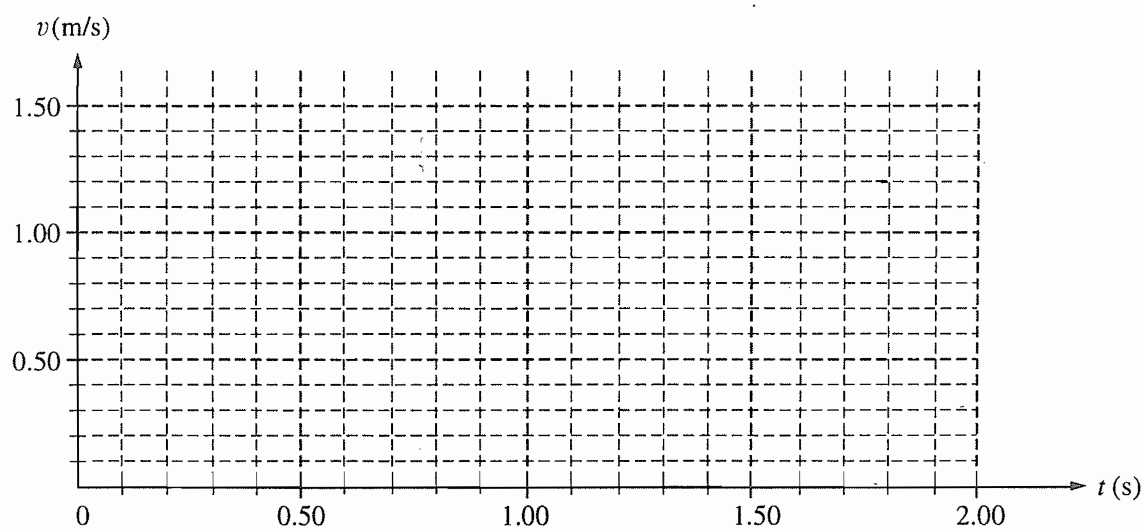
GO ON TO THE NEXT PAGE

(b) On the axes below, sketch a graph, consistent with the data above, of the speed of glider A as a function of time t for the 2.00 s interval.



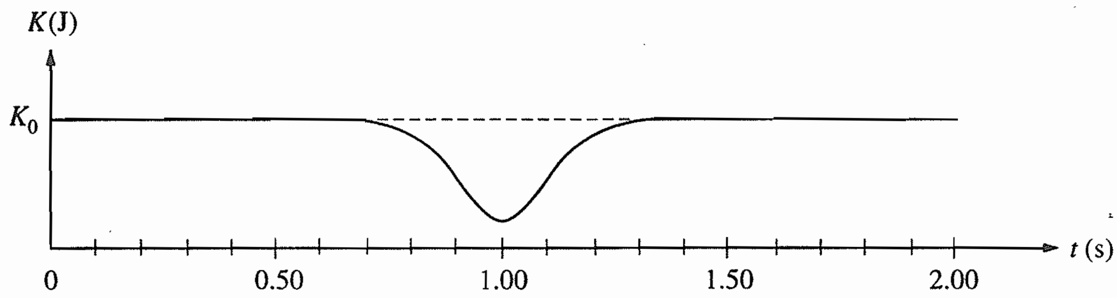
(c) i. Use the data to calculate the speed of glider B immediately after it separates from the spring.

ii. On the axes below, sketch a graph of the speed of glider B as a function of time t.



GO ON TO THE NEXT PAGE

A graph of the total kinetic energy K for the two-glider system over the 2.00 s interval has the following shape. K_0 is the total kinetic energy of the system at time $t = 0$.

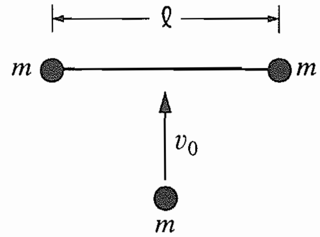


(d) i. Is the collision elastic? Justify your answer.

ii. Briefly explain why there is a minimum in the kinetic energy curve at $t = 1.00$ s.

GO ON TO THE NEXT PAGE

Mech. 2. A space shuttle astronaut in a circular orbit around the Earth has an assembly consisting of two small dense spheres, each of mass m, whose centers are connected by a rigid rod of length ℓ and negligible mass. The astronaut also has a device that will launch a small lump of clay of mass m at speed v_0. Express your answers in terms of m, v_0, ℓ, and fundamental constants.

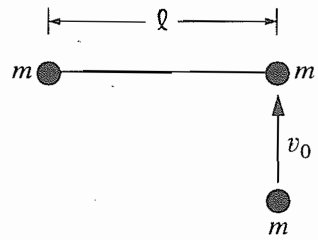


(a) Initially, the assembly is "floating" freely at rest relative to the cabin, and the astronaut launches the clay lump so that it perpendicularly strikes and sticks to the midpoint of the rod, as shown above.

i. Determine the total kinetic energy of the system (assembly and clay lump) after the collision.

ii. Determine the change in kinetic energy as a result of the collision.

GO ON TO THE NEXT PAGE



(b) The assembly is brought to rest, the clay lump removed, and the experiment is repeated as shown above, with the clay lump striking perpendicular to the rod but this time sticking to one of the spheres of the assembly.

i. Determine the distance from the left end of the rod to the center of mass of the system (assembly and clay lump) immediately after the collision. (Assume that the radii of the spheres and clay lump are much smaller than the separation of the spheres.)

ii. On the figure above, indicate the direction of the motion of the center of mass immediately after the collision.

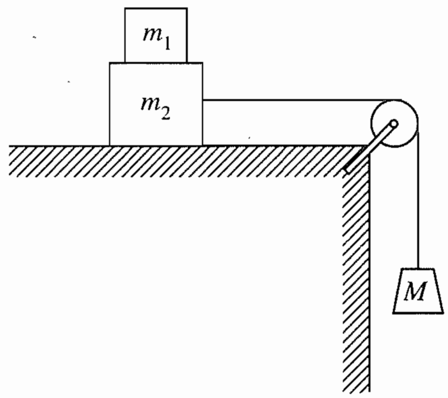
iii. Determine the speed of the center of mass immediately after the collision.

GO ON TO THE NEXT PAGE

iv. Determine the angular speed of the system (assembly and clay lump) immediately after the collision.

v. Determine the change in kinetic energy as a result of the collision.

GO ON TO THE NEXT PAGE



Mech. 3. Block 1 of mass m_1 is placed on block 2 of mass m_2, which is then placed on a table. A string connecting block 2 to a hanging mass M passes over a pulley attached to one end of the table, as shown above. The mass and friction of the pulley are negligible. The coefficients of friction between blocks 1 and 2 and between block 2 and the tabletop are nonzero and are given in the following table.

	Coefficient Between Blocks 1 and 2	Coefficient Between Block 2 and the Tabletop
Static	μ_{s1}	μ_{s2}
Kinetic	μ_{k1}	μ_{k2}

Express your answers in terms of the masses, coefficients of friction, and g, the acceleration due to gravity.

(a) Suppose that the value of M is small enough that the blocks remain at rest when released. For each of the following forces, determine the magnitude of the force and draw a vector on the block provided to indicate the direction of the force if it is nonzero.

i. The normal force N_1 exerted on block 1 by block 2

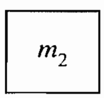
ii. The friction force f_1 exerted on block 1 by block 2

GO ON TO THE NEXT PAGE

iii. The force T exerted on block 2 by the string

iv. The normal force N_2 exerted on block 2 by the tabletop

v. The friction force f_2 exerted on block 2 by the tabletop



(b) Determine the largest value of M for which the blocks can remain at rest.

GO ON TO THE NEXT PAGE

(c) Now suppose that M is large enough that the hanging block descends when the blocks are released. Assume that blocks 1 and 2 are moving as a unit (no slippage). Determine the magnitude a of their acceleration.

(d) Now suppose that M is large enough that as the hanging block descends, block 1 is slipping on block 2. Determine each of the following.

i. The magnitude a_1 of the acceleration of block 1

ii. The magnitude a_2 of the acceleration of block 2

S T O P

END OF SECTION II, MECHANICS

IF YOU FINISH BEFORE TIME IS CALLED, YOU MAY CHECK YOUR WORK ON SECTION II, MECHANICS, ONLY. DO NOT TURN TO ANY OTHER TEST MATERIALS.

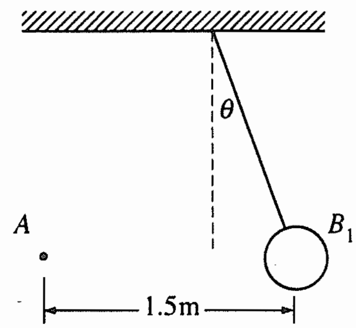
PHYSICS C

SECTION II, ELECTRICITY AND MAGNETISM

Time—45 minutes

3 Questions

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



Note: Figure not drawn to scale.

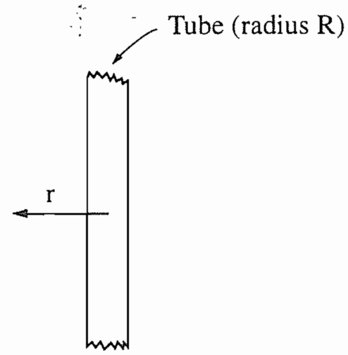
E & M. 1. The small sphere A in the diagram above has a charge of 120 μC. The large sphere B_1 is a thin shell of nonconducting material with a net charge that is uniformly distributed over its surface. Sphere B_1 has a mass of 0.025 kg, a radius of 0.05 m, and is suspended from an uncharged, nonconducting thread. Sphere B_1 is in equilibrium when the thread makes an angle $\theta = 20°$ with the vertical. The centers of the spheres are at the same vertical height and are a horizontal distance of 1.5 m apart, as shown.

(a) Calculate the charge on sphere B_1.

GO ON TO THE NEXT PAGE

(b) Suppose that sphere B_1 is replaced by a second suspended sphere B_2 that has the same mass, radius, and charge, but that is conducting. Equilibrium is again established when sphere A is 1.5 m from sphere B_2 and their centers are at the same vertical height. State whether the equilibrium angle θ_2 will be less than, equal to, or greater than 20°. Justify your answer.

The sphere B_2 is now replaced by a very long, horizontal, nonconducting tube, as shown in the top view below. The tube is hollow with thin walls of radius $R = 0.20$ m and a uniform positive charge per unit length of $\lambda = +0.10\ \mu C/m$.



Top View

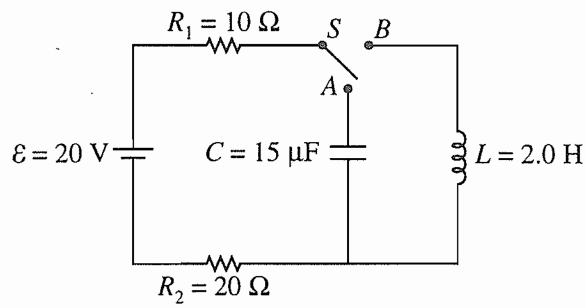
(c) Use Gauss's law to show that the electric field at a perpendicular distance r from the tube is given by the expression $E = \dfrac{1.8 \times 10^3}{r}$ N/C, where $r>R$ and r is in meters.

GO ON TO THE NEXT PAGE

(d) The small sphere A with charge 120 μC is now brought into the vicinity of the tube and is held at a distance of $r = 1.5$ m from the center of the tube. Calculate the repulsive force that the tube exerts on the sphere.

(e) Calculate the work done against the electrostatic repulsion to move sphere A toward the tube from a distance $r = 1.5$ m to a distance $r = 0.3$ m from the tube.

GO ON TO THE NEXT PAGE



E & M. 2. In the circuit shown above, the switch S is initially in the open position shown, and the capacitor is uncharged. A voltmeter (not shown) is used to measure the correct potential difference across resistor R_1.

(a) On the circuit diagram above, draw the voltmeter with the proper connections for correctly measuring the potential difference across resistor R_1.

(b) At time $t = 0$, the switch is moved to position A. Determine the voltmeter reading for the time immediately after $t = 0$.

(c) After a long time, a measurement of potential difference across R_1 is again taken. Determine for this later time each of the following.

i. The voltmeter reading

ii. The charge on the capacitor

GO ON TO THE NEXT PAGE

(d) At a still later time $t = T$, the switch S is moved to position B. Determine the voltmeter reading for the time immediately after $t = T$.

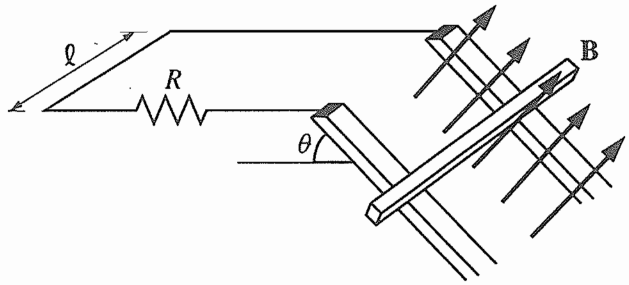
(e) A long time after $t = T$, the current in R_1 reaches a constant final value I_f.

i. Determine I_f.

ii. Determine the final energy stored in the inductor.

(f) Write, but do not solve, a differential equation for the current in resistor R_1 as a function of time t after the switch is moved to position B.

GO ON TO THE NEXT PAGE



E & M. 3. A conducting bar of mass m is placed on two long conducting rails a distance ℓ apart. The rails are inclined at an angle θ with respect to the horizontal, as shown above, and the bar is able to slide on the rails with negligible friction. The bar and rails are in a uniform and constant magnetic field of magnitude B oriented perpendicular to the incline. A resistor of resistance R connects the upper ends of the rails and completes the circuit as shown. The bar is released from rest at the top of the incline. Express your answers to parts (a) through (d) in terms of m, ℓ, θ, B, R, and g.

(a) Determine the current in the circuit when the bar has reached a constant final speed.

(b) Determine the constant final speed of the bar.

GO ON TO THE NEXT PAGE

(c) Determine the rate at which energy is being dissipated in the circuit when the bar has reached its constant final speed.

(d) Express the speed of the bar as a function of time t from the time it is released at $t = 0$.

(e) Suppose that the experiment is performed again, this time with a second identical resistor connecting the rails at the bottom of the incline. Will this affect the final speed attained by the bar, and if so, how? Justify your answer.

STOP

END OF SECTION II, ELECTRICITY AND MAGNETISM

IF YOU FINISH BEFORE TIME IS CALLED, YOU MAY CHECK YOUR WORK ON SECTION II, ELECTRICITY AND MAGNETISM, ONLY. DO NOT TURN TO ANY OTHER TEST MATERIALS.

Chapter V Answers to the 1998 AP Physics C Examination

- Section I: Multiple Choice
  - Blank Answer Sheet
- Section II: Free Response

Section I: Multiple Choice

Listed below are the correct answers to the multiple-choice questions and the percentage of AP candidates who answered each question correctly.

Answer Key and Percent Answering Correctly

Mechanics			Electricity & Magnetism		
Item No.	Correct Answer	Percent Correct	Item No.	Correct Answer	Percent Correct
1	B	82%	36	B	74%
2	E	82%	37	E	65%
3	D	78%	38	C	77%
4	B	67%	39	E	93%
5	C	69%	40	D	79%
6	A	56%	41	C	56%
7	A	56%	42	D	75%
8	D	45%	43	D	29%
9	D	18%	44	A	75%
10	A	53%	45	C	80%
11	E	45%	46	E	61%
12	C	68%	47	D	34%
13	C	81%	48	C	45%
14	B	61%	49	A	49%
15	A	42%	50	D	33%
16	C	54%	51	A	28%
17	A	50%	52	C	45%
18	B	82%	53	E	50%
19	A	35%	54	E	63%
20	B	18%	55	B	26%
21	D	89%	56	E	50%
22	E	42%	57	A	19%
*23	—	—	58	A	53%
24	A	67%	59	C	50%
25	B	56%	60	B	24%
26	C	63%	61	A	74%
27	D	46%	62	D	64%
28	C	59%	63	E	39%
29	E	29%	64	B	71%
30	B	71%	65	D	27%
31	E	48%	66	B	46%
32	E	65%	67	A	24%
33	B	36%	68	E	30%
34	A	37%	69	B	62%
35	D	58%	70	A	61%

*This question was not counted when the exam was scored.

Section II: Free Response

On the next several pages, you will find a general analysis of each question, and the students' performance on it, by the Chief Faculty Consultant. Following these are the scoring guidelines used by the faculty consultants at the AP Reading. There are also sample student responses for each question, along with comments indicating why they received the score they did. A distribution of student scores on each free-response question is given on page 218.

Mechanics Question 1 (15 points) — Scoring Guidelines

This question, while not at all difficult from a calculational point of view, provides an excellent test of conceptual understanding. The format in which the information is provided in this question gives it an experimental flavor. Not only does the question test the student's understanding of energy and momentum concepts, but also the ability to extract the necessary information from data which is graphically presented. A correct answer requires an understanding of the relationship between displacement, velocity, and time for both accelerated and non-accelerated motion. In general, students performed very well on this question.

Distribution of points

(a)

i. 1 point
For correct answer — 1 point

$$\bar{v} = \frac{\Delta s}{\Delta t} = \frac{0.30\,\text{m} - 0.10\,\text{m}}{0.30\,\text{s} - 0.10\,\text{s}} = 1.00\,\text{m/s}$$

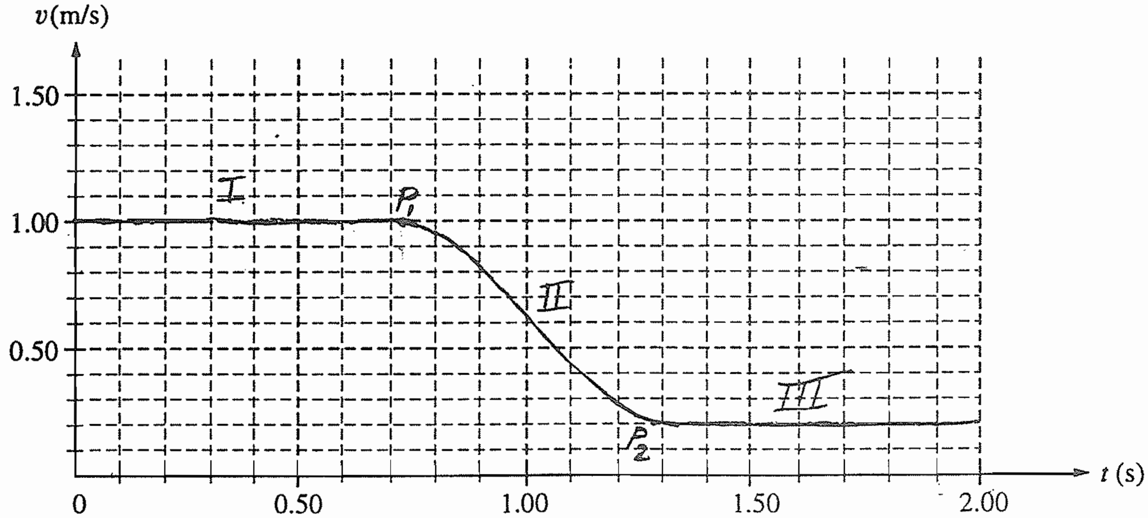
ii. 1 point
For correct answer — 1 point

$$\bar{v} = \frac{\Delta s}{\Delta t} = \frac{0.99\,\text{m} - 0.87\,\text{m}}{1.10\,\text{s} - 0.90\,\text{s}} = 0.60\,\text{m/s}$$

iii. 1 point
For correct answer — 1 point

$$\bar{v} = \frac{\Delta s}{\Delta t} = \frac{1.18\,\text{m} - 1.14\,\text{m}}{1.90\,\text{s} - 1.70\,\text{s}} = 0.20\,\text{m/s}$$

(b) 3 points



For line I horizontal at $v = 1.00$ m/s or at answer obtained for (a)i. — 1 point

For line II with monotonic, negative slope between points P_1 and P_2,
P_1 at (0.70 - 0.80, 1.00) or (0.70 - 0.80, answer to (a)i.), and
P_2 at (1.20 - 1.30, 0.20) or (1.20 - 1.30, answer to (a)iii.) — 1 point
(This line may be straight, which is consistent with the data, or slightly curved as shown, which is consistent with the behavior of springs)

For line III horizontal at $v = 0.20$ m/s or at answer obtained for (a)iii. — 1 point

Distribution of points

Mech. 1 (continued)

(c)

i. 3 points

For any statement of conservation of momentum or energy — 1 point

For proper conservation of momentum or energy equation — 1 point

Method 1: Conservation of momentum

$$m_A v_{Ai} = m_A v_{Af} + m_B v_B$$

$$(0.90\text{ kg})(1.00\text{ m/s}) = (0.90\text{ kg})(0.20\text{ m/s}) + (0.60\text{ kg})v_B$$

Method 2: Recognize from part (d) that energy is also conserved.

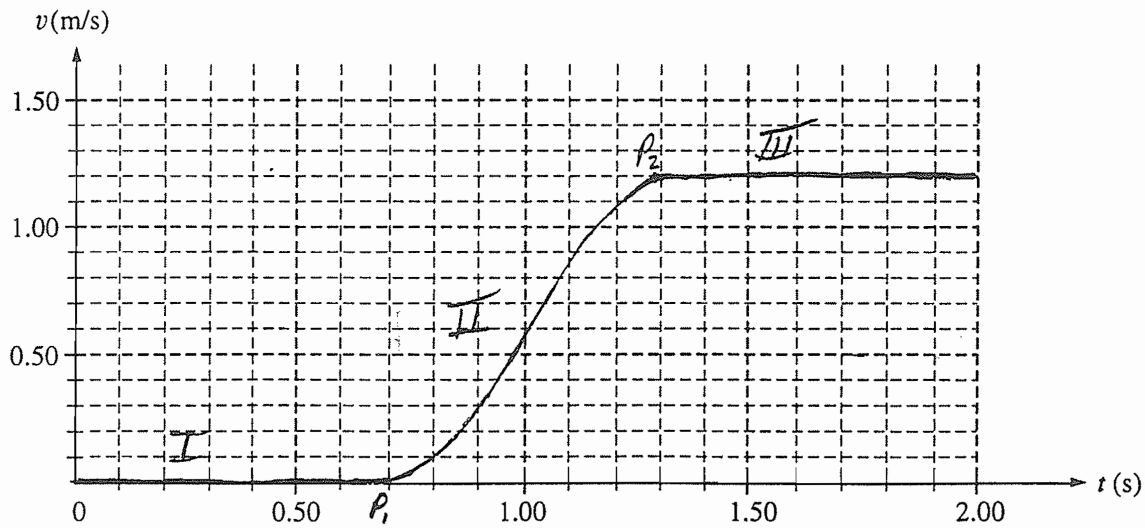
$$\frac{1}{2}m_A v_{Ai}^2 = \frac{1}{2}m_A v_{Af}^2 + \frac{1}{2}m_B v_B^2$$

$$\frac{1}{2}(0.90\text{ kg})(1.00\text{ m/s})^2 = \frac{1}{2}(0.90\text{ kg})(0.20\text{ m/s})^2 + \frac{1}{2}(0.60\text{ kg})v_B^2$$

For correct answer — 1 point

$v_B = 1.2$ m/s

ii. 3 points



For line I horizontal at $v = 0$ — 1 point

For line II with monotonic, positive slope between points P_1 and P_2,

P_1 at (0.70 - 0.80, 0), and

P_2 at (1.20 - 1.30, 1.20) or (1.20 - 1.30, answer to (c)i.) — 1 point

(This line may be straight, which is consistent with the data, or slightly curved as shown, which is consistent with the behavior of springs)

For line III horizontal at v = 1.20 m/s or at answer obtained for (c)i. — 1 point

Distribution of points

Mech. 1 (continued)

(d)

i. 2 points

For correct answer — 1 point

Yes, the collision is elastic.

For any reasonable justification — 1 point

Examples:

The final kinetic energy equals the initial kinetic energy.

The spring force is conservative meaning the total energy stored equals the total energy released.

The compressed spring stores and releases energy in equal amounts.

(The justification point was not awarded if student answered "no" to the question.)

ii. 1 point

For any reasonable explanation — 1 point

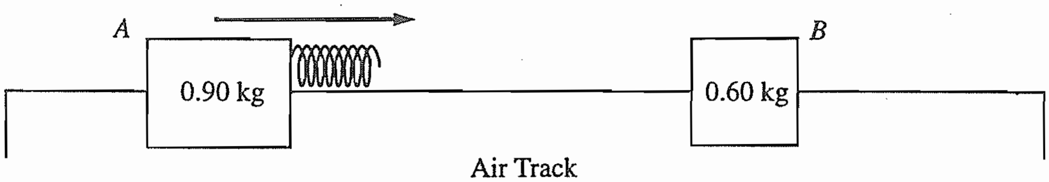
Examples:

The compressed spring stores maximum amount of kinetic energy.

At time t = 1 s, there is maximum kinetic energy stored as potential energy.

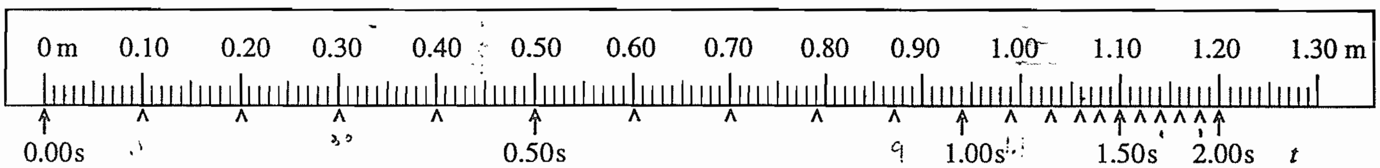
At time t = 1 s, the spring has maximum potential or elastic energy.

Excellent Student Response: 15 points



Mech. 1. Two gliders move freely on an air track with negligible friction, as shown above. Glider A has a mass of 0.90 kg and glider B has a mass of 0.60 kg. Initially, glider A moves toward glider B, which is at rest. A spring of negligible mass is attached to the right side of glider A. Strobe photography is used to record successive positions of glider A at 0.10 s intervals over a total time of 2.00 s, during which time it collides with glider B.

The following diagram represents the data for the motion of glider A. Positions of glider A at the end of each 0.10 s interval are indicated by the symbol $\wedge$ against a metric ruler. The total elapsed time t after each 0.50 s is also indicated.



(a) Determine the average speed of glider A for the following time intervals.

i. 0.10 s to 0.30 s

$$\bar{v} = d/t = \frac{.2m}{.2s} = 1\ m/s$$

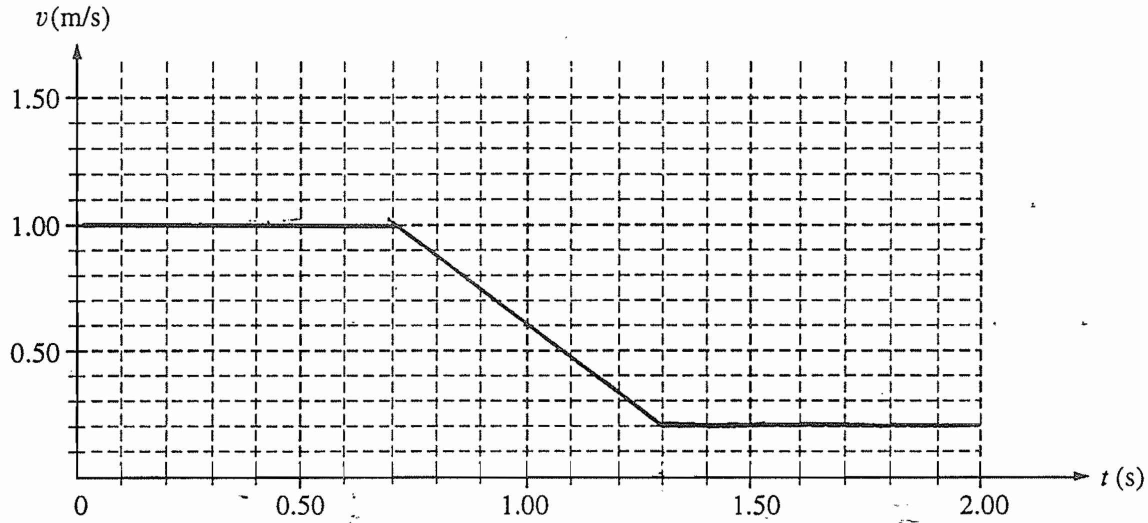
ii. 0.90 s to 1.10 s

$$\bar{v} = d/t = \frac{.99m - .87m}{.2s} = \frac{.12m}{.2s} = .6\ m/s$$

iii. 1.70 s to 1.90 s

$$\bar{v} = d/t = \frac{1.18m - 1.14m}{.2s} = \frac{.04m}{.2s} = .2\ m/s$$

(b) On the axes below, sketch a graph, consistent with the data above, of the speed of glider A as a function of time t for the 2.00 s interval.



(c) i. Use the data to calculate the speed of glider B immediately after it separates from the spring.

A

$KE_i = \frac{1}{2}mv_i^2$
$= \frac{1}{2}(.9\,kg)(1\,m/s)^2$
$= .45\,J$

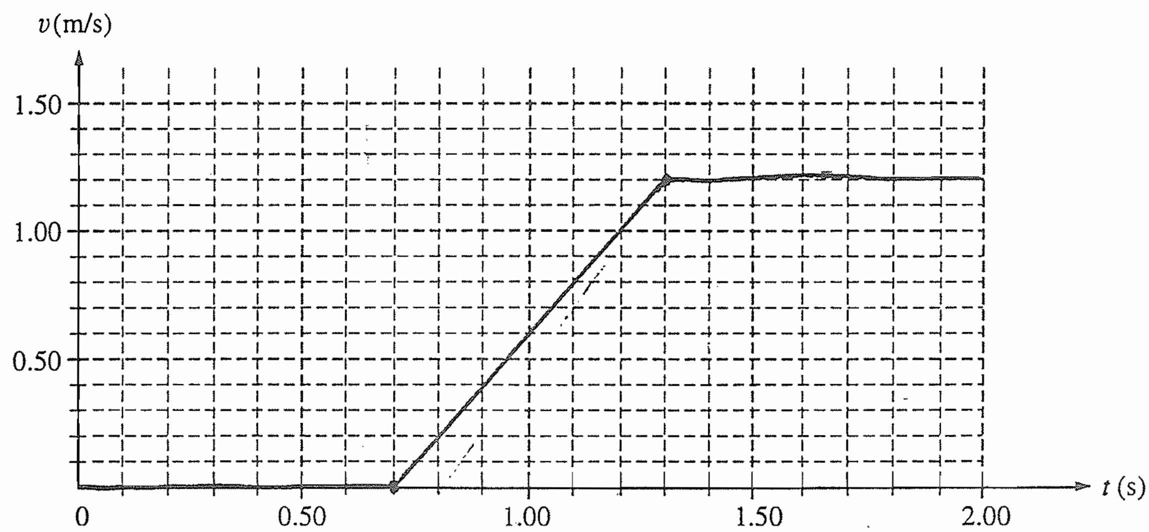
$KE_f = \frac{1}{2}mv_f^2$
$= \frac{1}{2}(.9\,kg)(.2\,m/s)^2$
$= .018\,J$

$\Delta KE = .45\,J - .018\,J = .432\,J$

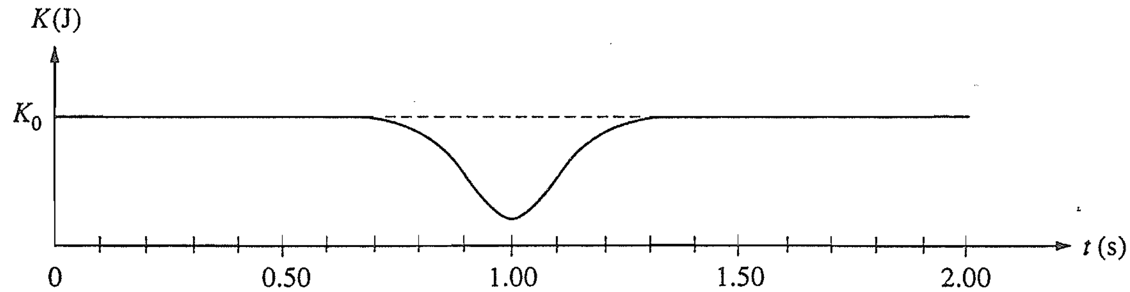
B

$KE = \frac{1}{2}mv^2$
$.432\,J = \frac{1}{2}(.6\,kg)v^2$
$1.44\,m^2/s^2 = v^2$
$1.2\,m/s = v$

ii. On the axes below, sketch a graph of the speed of glider B as a function of time t.



A graph of the total kinetic energy K for the two-glider system over the 2.00 s interval has the following shape. K_0 is the total kinetic energy of the system at time $t = 0$.



(d) i. Is the collision elastic? Justify your answer.

Yes the collision is elastic. This is so because momentum is conserved ($m_A v_i = m_A v_f + m_B v_f$) and so is Kinetic Energy. If this were an inelastic collision, then KE would not be conserved because it would be lost during the deformation of the objects and it would be converted into heat energy with all the rubbing the objects would do against each other.

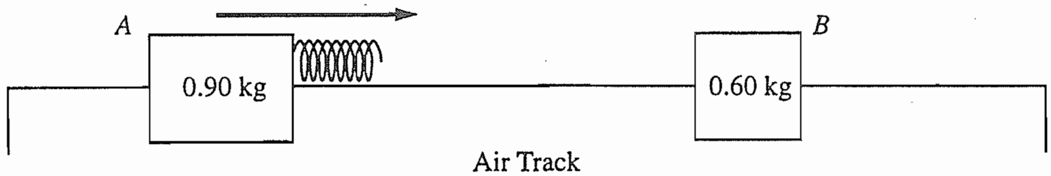
ii. Briefly explain why there is a minimum in the kinetic energy curve at $t = 1.00$ s.

That is the point at which the spring between the objects is completely compressed. Therefore the objects are barely moving, and most of their kinetic energy has gone into potential energy stored in the spring.

Commentary:

While this student does not explicitly make a statement of conservation of energy for part (c)i, it is implicit in the calculations that are shown. Both explanations for part (d) include the important ideas required.

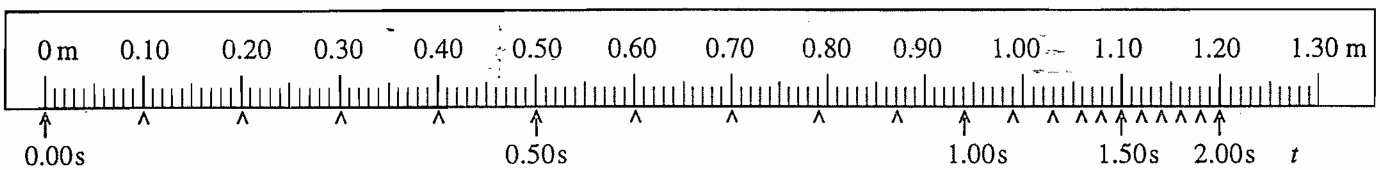
Very Good Student Response: 13 points



Air Track

Mech. 1. Two gliders move freely on an air track with negligible friction, as shown above. Glider A has a mass of 0.90 kg and glider B has a mass of 0.60 kg. Initially, glider A moves toward glider B, which is at rest. A spring of negligible mass is attached to the right side of glider A. Strobe photography is used to record successive positions of glider A at 0.10 s intervals over a total time of 2.00 s, during which time it collides with glider B.

The following diagram represents the data for the motion of glider A. Positions of glider A at the end of each 0.10 s interval are indicated by the symbol ∧ against a metric ruler. The total elapsed time t after each 0.50 s is also indicated.



(a) Determine the average speed of glider A for the following time intervals.

i. 0.10 s to 0.30 s

Ave sd. $= \frac{x_2 - x_1}{t_2 - t_1} = \frac{.3\text{m} - 0\text{m}}{.30\text{s} - .00\text{s}} = \frac{.3\text{ m}}{.3\text{ s}} = 1.00\text{ m/s}$

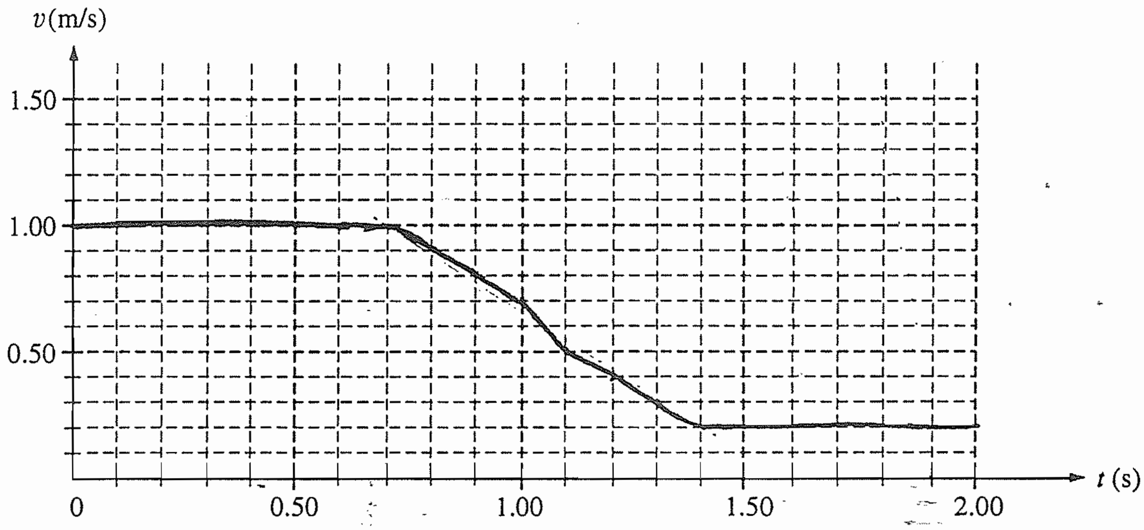
ii. 0.90 s to 1.10 s

$\frac{x_2 - x_1}{t_2 - t_1} = \frac{.99\text{m} - .87\text{m}}{1.10\text{s} - .90\text{s}} = 0.60\text{ m/s}$

iii. 1.70 s to 1.90 s

$\frac{x_2 - x_1}{t_2 - t_1} = \frac{1.18\text{m} - 1.14\text{m}}{1.90\text{s} - 1.70\text{s}} = 0.20\text{ m/s}$

(b) On the axes below, sketch a graph, consistent with the data above, of the speed of glider A as a function of time t for the 2.00 s interval.



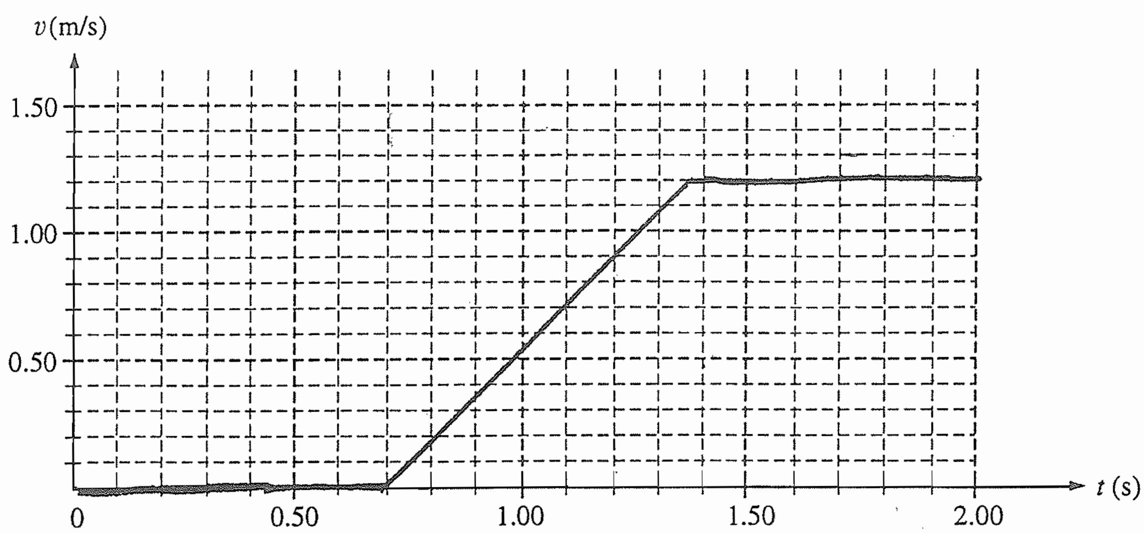
(c) i. Use the data to calculate the speed of glider B immediately after it separates from the spring.

$$m_A V_A + m_B V_B = m_A V_A + M_B V_B$$

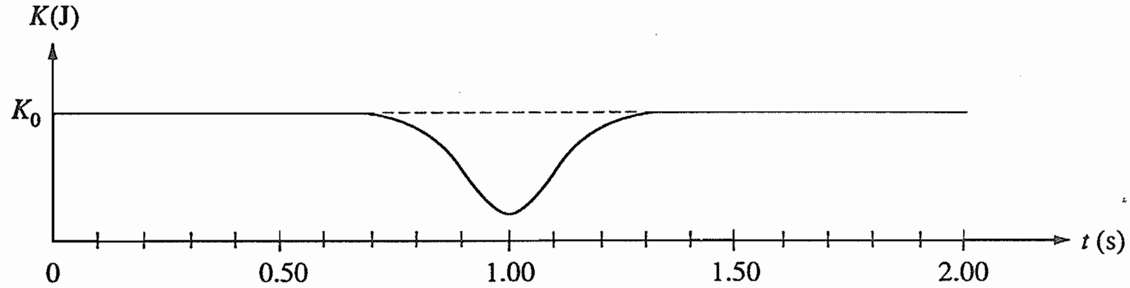
$$(.90\,kg)(1.00\,m/s) + (.60\,kg)(0\,m/s) = (.90\,kg)(.20\,m/s) + (.60\,kg)(V_B)$$

$$V_B = 1.20\,m/s$$

ii. On the axes below, sketch a graph of the speed of glider B as a function of time t.



A graph of the total kinetic energy K for the two-glider system over the 2.00 s interval has the following shape. K_0 is the total kinetic energy of the system at time $t = 0$.



(d) i. Is the collision elastic? Justify your answer.

Yes, both kinetic energy and momentum are conserved.

K before collision = K_0

K after collision = K_0

Masses of both gliders are constant.

ii. Briefly explain why there is a minimum in the kinetic energy curve at $t = 1.00$ s.

Some of the kinetic energy of the gliders is temperarily converted to potential energy within the compressed spring. This Potential energy is eventually converted back into kinetic energy.

Commentary:

This student does as well with the calculations and explanations as the previous paper, but point P_2 is incorrect in both graphs.

Mechanics Question 2 (15 points) — Scoring Guidelines

This question tests understanding of the concepts of linear and angular momentum conservation, kinetic energy, and center of mass. Just as importantly, the student must understand when kinetic energy is, and is not, conserved. Many students incorrectly assumed that kinetic energy was conserved in these decidedly inelastic collisions. This problem involved no complicated calculations, but rather required real understanding of motion of the center of mass and motion about the center of mass for a correct solution.

Distribution of points

(a)

i. 3 points

For a statement that momentum is conserved <u>or</u> $\mathbf{p}_i = \mathbf{p}_f$ — 1 point

$$mv_0 = (3m)v_f$$

For the correct final speed — 1 point

$$v_f = \frac{v_0}{3}$$

For correct substitutions and answer — 1 point

$$K_{after} = \frac{1}{2}Mv^2 = \frac{1}{2}(3m)\left(\frac{v_0}{3}\right)^2 = \frac{mv_0^2}{6}$$

(1 point awarded for $K_{after} = \frac{1}{2}(3m)v_f^2$ if student found wrong v_f or could not find v_f.)

ii. 2 points

$$\Delta K = K_{after} - K_{before} = \frac{mv_0^2}{6} - \frac{mv_0^2}{2}$$

For correct sign of answer — 1 point

For correct magnitude of answer — 1 point

$$\Delta K = -\frac{mv_0^{\,2}}{3}$$

(2 points awarded for any wrong answer from (a)i. minus $\frac{1}{2}mv_0^2$.)

(1 point awarded for $\frac{1}{2}mv_0^2$ minus any wrong answer from (a)i.)

Mech. 2 (continued)

(b)

i. 2 points

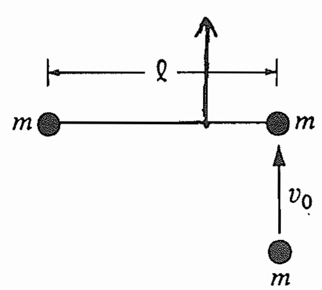
For correct substitutions into the center of mass equation — 1 point

$$r_{cm} = \frac{\Sigma m_i r_i}{\Sigma m_i} = \frac{m(0) + 2m(\ell)}{m + 2m}$$

For correct answer — 1 point

$$r_{cm} = \frac{2}{3}\ell$$

ii. 1 point



For vertical arrow anywhere on diagram or in answer space — 1 point

iii. 1 point

Linear momentum is conserved.

$\mathbf{p}_i = \mathbf{p}_f$

$mv_0 + 3m(0) = (3m)v_f$

For correct answer — 1 point

$$v_f = \frac{v_0}{3}$$

Distribution of points

Mech. 2 (continued)

iv. 3 points

Angular momentum is conserved.

$L_{\text{before}} = L_{\text{after}}$

For determining the angular momenta about the center of mass — 1 point

$$L_{before} = mv_0 R\sin\theta = mv_0\left(\frac{1}{3}\ell\right)$$

$$L_{after} = \omega I$$

For determining the moment of inertia — 1 point

$$I = \Sigma mr^2 = m\left(\frac{2}{3}\ell\right)^2 + 2m\left(\frac{1}{3}\ell\right)^2 = \frac{2}{3}m\ell^2$$

Substituting into $L_{\text{before}} = L_{\text{after}}$,

$$mv_0\left(\frac{1}{3}\ell\right) = \frac{2}{3}m\ell^2\omega$$

For correct answer — 1 point

$$\omega = \frac{v_0}{2\ell}$$

v. 3 points

$$K_i = \frac{1}{2}mv_0^2$$

For recognizing that final kinetic energy is translational plus rotational — 1 point

$$K_f = \frac{1}{2}mv_f^2 + \frac{1}{2}I\omega^2$$

For correct substitutions and final kinetic energy — 1 point

$$K_f = \frac{1}{2}(3m)\left(\frac{v_0}{3}\right)^2 + \frac{1}{2}\left(\frac{2}{3}m\ell^2\right)\left(\frac{v_0}{2\ell}\right)^2 = \frac{1}{4}mv_0^2$$

$$\Delta K = K_f - K_i = \frac{1}{4}mv_0^2 - \frac{1}{2}mv_0^2$$

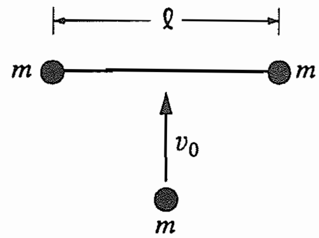
For correct answer — 1 point

$$\Delta K = -\frac{1}{4}m{v_0}^2$$

(Correct answer point awarded for either positive or negative sign.)

Excellent Student Response: 15 points

Mech. 2. A space shuttle astronaut in a circular orbit around the Earth has an assembly consisting of two small dense spheres, each of mass m, whose centers are connected by a rigid rod of length ℓ and negligible mass. The astronaut also has a device that will launch a small lump of clay of mass m at speed v_0. Express your answers in terms of m, v_0, ℓ, and fundamental constants.



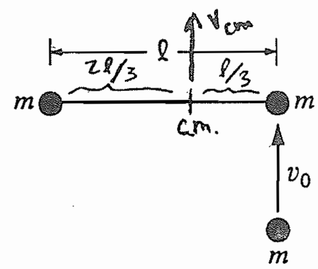
(a) Initially, the assembly is "floating" freely at rest relative to the cabin, and the astronaut launches the clay lump so that it perpendicularly strikes and sticks to the midpoint of the rod, as shown above.

i. Determine the total kinetic energy of the system (assembly and clay lump) after the collision.

$$mV_0 = (m+2m)V_f$$
$$mV_0 = 3mV_f$$
$$V_f = \frac{V_0}{3}$$
$$KE_f = \frac{1}{2}(3m)V_f^2 = \frac{1}{2}(3m)\left(\frac{V_0}{3}\right)^2 = \boxed{\frac{1}{6}mV_0^2}$$

ii. Determine the change in kinetic energy as a result of the collision.

$$\Delta KE = KE_f - KE_0$$
$$= \frac{1}{6}mV_0^2 - \frac{1}{2}mV_0^2$$
$$\boxed{\Delta KE = -\frac{1}{3}mV_0^2}$$



(b) The assembly is brought to rest, the clay lump removed, and the experiment is repeated as shown above, with the clay lump striking perpendicular to the rod but this time sticking to one of the spheres of the assembly.

i. Determine the distance from the left end of the rod to the center of mass of the system (assembly and clay lump) immediately after the collision. (Assume that the radii of the spheres and clay lump are much smaller than the separation of the spheres.) (since radii of spheres are neglible)

$$X_{cm} = \frac{(2m)\,\ell}{m+2m} = \frac{2m\ell}{3m} = \boxed{\frac{2}{3}\ell}$$

ii. On the figure above, indicate the direction of the motion of the center of mass immediately after the collision.

iii. Determine the speed of the center of mass immediately after the collision.

$$mV_0 = (3m)\,V_{cm.f}$$

$$\boxed{V_{cm_f} = \frac{mV_0}{3m} = \frac{V_0}{3}}$$

iv. Determine the angular speed of the system (assembly and clay lump) immediately after the collision.

$L_o = L_f$

$r \times p_o = I\omega_f$

$m\left(\frac{\ell}{3}\right)v_o \sin 90° = \left(m\left(\frac{2\ell}{3}\right)^2 + 2m\left(\frac{\ell}{3}\right)^2\right)\omega_f$

$\frac{m\ell v_o}{3} = \left(\frac{4m\ell^2}{9} + \frac{2m\ell^2}{9}\right)\omega_f$

$\frac{1}{3}\cancel{m}\cancel{\ell}v_o = \frac{2}{3}\cancel{m}\ell^{\cancel{2}}\omega_f$

$\boxed{\omega_f = \frac{v_o}{2\ell}}$

v. Determine the change in kinetic energy as a result of the collision.

$\Delta KE = KE_f - KE_o$

$\Delta KE = \frac{1}{2}(3m)v_{cm_f}^2 + \frac{1}{2}I\omega_f^2 - \frac{1}{2}mv_o^2$

$= \frac{1}{2}(3m)\left(\frac{v_o}{3}\right)^2 + \frac{1}{2}\left(\frac{2}{3}m\ell^2\right)\left(\frac{v_o}{2\ell}\right)^2 - \frac{1}{2}mv_o^2$

$= \frac{1}{6}mv_o^2 + \frac{1}{12}mv_o^2 - \frac{1}{2}mv_o^2$

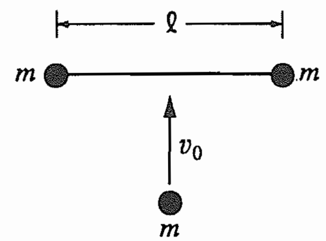
$= \frac{1}{4}mv_o^2 - \frac{1}{2}mv_o^2 = \boxed{-\frac{1}{4}mv_o^2}$

Commentary:

In addition to being completely correct, this solution is neat and well organized; the student shows an excellent understanding of the principles involved.

Very Good Student Response: 13 points

Mech. 2. A space shuttle astronaut in a circular orbit around the Earth has an assembly consisting of two small dense spheres, each of mass m, whose centers are connected by a rigid rod of length ℓ and negligible mass. The astronaut also has a device that will launch a small lump of clay of mass m at speed v_0. Express your answers in terms of m, v_0, ℓ, and fundamental constants.



(a) Initially, the assembly is "floating" freely at rest relative to the cabin, and the astronaut launches the clay lump so that it perpendicularly strikes and sticks to the midpoint of the rod, as shown above.

i. Determine the total kinetic energy of the system (assembly and clay lump) after the collision.

$$\cancel{m}V_0 = 3\cancel{m}V_f$$

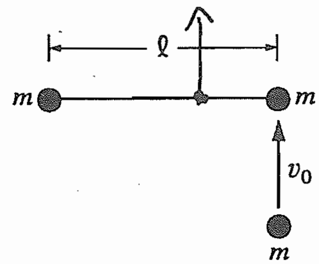
$$V_f = \frac{V_0}{3}$$

$$KE_{final} = \frac{1}{2}mV^2 = \frac{1}{2} \times 3m \times \left(\frac{V_0}{3}\right)^2 = \frac{1}{6}mV_0^2$$

ii. Determine the change in kinetic energy as a result of the collision.

$$KE_{initial} - KE_{final} = \Delta KE$$

$$\frac{1}{2}mV_0^2 - \frac{1}{6}mV_0^2 = \frac{1}{3}mV_0^2$$



(b) The assembly is brought to rest, the clay lump removed, and the experiment is repeated as shown above, with the clay lump striking perpendicular to the rod but this time sticking to one of the spheres of the assembly.

i. Determine the distance from the left end of the rod to the center of mass of the system (assembly and clay lump) immediately after the collision. (Assume that the radii of the spheres and clay lump are much smaller than the separation of the spheres.)

Center of mass $= \dfrac{m \times 0 + 2m \times \ell}{3m} = \dfrac{2}{3}\ell$ ~~from~~

ii. On the figure above, indicate the direction of the motion of the center of mass immediately after the collision.

iii. Determine the speed of the center of mass immediately after the collision.

$mV_0 = 3mV_f$

$V_f = \dfrac{V_0}{3}$

iv. Determine the angular speed of the system (assembly and clay lump) immediately after the collision.

$$I_{clay}\omega_{clay} = I_f \omega_f \qquad I_{clay} = m\left(\frac{1}{3}l\right)^2 = \frac{ml^2}{9}$$

$$\frac{ml^{\cancel{2}}}{9} \times \frac{V_0}{\frac{1}{3}\cancel{l}} = \left[2m\left(\frac{1}{3}l\right)^2 + m\left(\frac{2}{3}l\right)^2\right]\omega_f$$

$$\frac{mlV_0}{3} = \left[\frac{2ml^2}{9} + \frac{4ml^2}{9}\right]\omega_f$$

$$\frac{\cancel{m}\cancel{l}V_0}{\cancel{3}} = \frac{2\cancel{m}l^{\cancel{2}}}{\cancel{3}}\omega_f$$

$$\omega_f = \frac{V_0}{2l}$$

v. Determine the change in kinetic energy as a result of the collision.

$$\Delta KE = \Delta KE_{linear} + \Delta KE_{angular}$$

$$\Delta KE_{angular} = \frac{1}{2}I_f\omega_f^2 \cancel{- \frac{1}{2}I_{clay}\omega_{clay}^2}$$

$$= \frac{1}{\cancel{2}} \times \frac{\cancel{2}ml^{\cancel{2}}}{3} \times \left(\frac{V_0}{2\cancel{l}}\right)^2 \cancel{- \frac{1}{2}m\left(\frac{1}{3}l\right)^2\left(\frac{V_0}{\frac{1}{3}l}\right)^2}$$

$$= \frac{mV_0^2}{12} \cancel{\frac{mV_0^2}{}}$$

$$\Delta KE_{linear} = \frac{1}{2}mv^2 = \frac{1}{2} \times 3m \times \left(\frac{V_0}{3}\right)^2 = \frac{mV_0^2}{6}$$

$$\Delta KE = \frac{mV_0^2}{12} + \frac{mV_0^2}{6} = \frac{3mV_0^2}{12} = \frac{mV_0^2}{4}$$

Commentary:

This student shows a very good understanding of the problem. The answer to part (a)ii does not have the correct sign, and the student only calculates the final kinetic energy, not the total energy, in the last part.

Mechanics Question 3 (15 points) — Scoring Guidelines

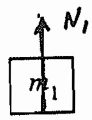
This question deals with application of Newton's 2nd and 3rd laws to a system of objects. Although a somewhat complicated problem, this complexity is mitigated by the first part of the question, which requires the student to think carefully about the forces acting on each of the parts of the system and their interrelationships.

Distribution of points

(a) 5 points

For each correct vector -- ½ point
For each correct magnitude -- ½ point
If the score for part (a) contained an odd number of half-points, the total score was truncated by dropping one half-point.

i.

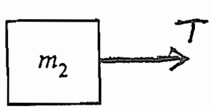


$N_1 = m_1 g$ — 1 point

ii.

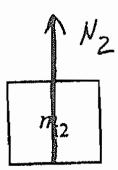
$f_1 = 0$ — 1 point

iii.



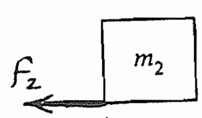
$T = Mg$ — 1 point

iv.



$N_2 = (m_1 + m_2)g$ — 1 point

v.



$f_2 = Mg$ — 1 point

(b) 3 points

For expression for the maximum frictional force — 1 point
$f_{2(\max)} = \mu_{s2} N_2 = \mu_{s2}(m_1 + m_2)g$

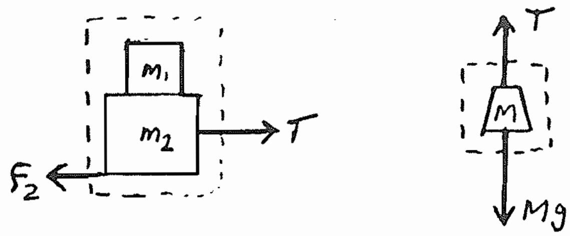
For equating this force to the tension $T = Mg$ — 1 point
$Mg = \mu_{s2}(m_1 + m_2)g$

For the correct answer — 1 point
$M = \mu_{s2}(m_1 + m_2)$

Distribution of points

Mech. 3 (continued)

(c) 3 points



For correctly applying Newton's second law to the hanging block — 1 point

$\Sigma \mathbf{F} = m\mathbf{a}$

$Mg - T = Ma$ (equation 1)

For correctly applying Newton's second law to the system of the two blocks on the plane — 1 point

$\Sigma \mathbf{F} = (m_1 + m_2)\mathbf{a}$

$T - f_2 = (m_1 + m_2)a$ (equation 2)

For combining equations 1 and 2 to eliminate T, substituting for f_2 and solving for a — 1 point

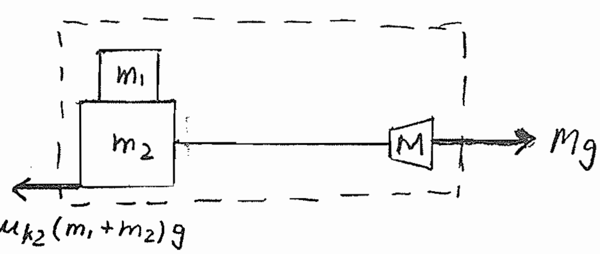
For example, solve each equation for T and set them equal.

$f_2 + (m_1 + m_2)a = Mg - Ma$

$\mu_{k2}(m_1 + m_2)g + (m_1 + m_2)a = Mg - Ma$

$$a = \left[\frac{M - \mu_{k2}(m_1 + m_2)}{M + m_1 + m_2}\right]g$$

(*Alternate solution*) — (*Alternate points*)



Apply Newton's second law to the three-block system, realizing that the pulley acts only to change the direction of the force produced by the tension in the string.

$\Sigma \mathbf{F} = m_s\mathbf{a}$

For correct substitutions in left side of equation above — *1 point*

For correct substitutions in right side of equation above — *1 point*

$Mg - \mu_{k2}(m_1 + m_2)g = (M + m_1 + m_2)a$

For correct solution for a — *1 point*

$$a = \left[\frac{M - \mu_{k2}(m_1 + m_2)}{M + m_1 + m_2}\right]g$$

Distribution of points

Mech. 3 (continued)

(d)
i. 2 points

$$a_1 = \frac{f_1}{m_1}$$

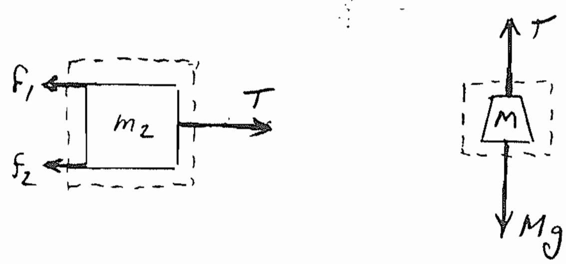
For correct value of f_1 — 1 point

$$f_1 = \mu_{k1} m_1 g$$

For correct answer — 1 point

$$a_1 = \frac{\mu_{k1} m_1 g}{m_1} = \mu_{k1} g$$

ii. 2 points



Apply Newton's second law to the hanging block.

$\Sigma \mathbf{F} = m\mathbf{a}$

$Mg - T = Ma_2$ (equation 1)

For correctly applying Newton's second law to block 2 — 1 point

$\Sigma \mathbf{F} = m\mathbf{a}$

$T - f_1 - f_2 = m_2 a_2$ (equation 2)

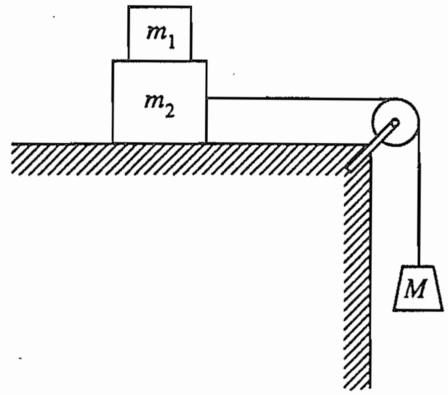
For combining equations 1 and 2 to eliminate T, substituting for the frictional forces and solving for a_2. — 1 point

For example, solve each equation for T and set them equal.

$f_1 + f_2 + m_2 a_2 = Mg - Ma_2$

$Ma_2 + m_2 a_2 = Mg - \mu_{k1} m_1 g - \mu_{k2}(m_1 + m_2) g$

$$a_2 = \left[\frac{M - \mu_{k1} m_1 - \mu_{k2}(m_1 + m_2)}{M + m_2}\right] g$$



Mech. 3. Block 1 of mass m_1 is placed on block 2 of mass m_2, which is then placed on a table. A string connecting block 2 to a hanging mass M passes over a pulley attached to one end of the table, as shown above. The mass and friction of the pulley are negligible. The coefficients of friction between blocks 1 and 2 and between block 2 and the tabletop are nonzero and are given in the following table.

	Coefficient Between Blocks 1 and 2	Coefficient Between Block 2 and the Tabletop
Static	μ_{s1}	μ_{s2}
Kinetic	μ_{k1}	μ_{k2}

Express your answers in terms of the masses, coefficients of friction, and g, the acceleration due to gravity.

(a) Suppose that the value of M is small enough that the blocks remain at rest when released. For each of the following forces, determine the magnitude of the force and draw a vector on the block provided to indicate the direction of the force if it is nonzero.

i. The normal force N_1 exerted on block 1 by block 2

m_1 $N_1 = m_1 g$

$m_1 g$

ii. The friction force f_1 exerted on block 1 by block 2

m_1

~~$f_1 = \mu_{s1} m_1 g$~~

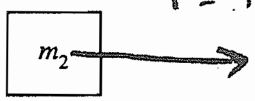
~~$f_1 = T = Mg$~~

0

(No force to resist)

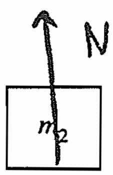
iii. The force T exerted on block 2 by the string

$T = Mg$



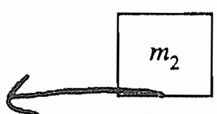
iv. The normal force N_2 exerted on block 2 by the tabletop

$N_2 = (m_1 + m_2)g$



v. The friction force f_2 exerted on block 2 by the tabletop

$f = \mu F_N$



$f_2 = \mu_{s2}(m_1 + m_2)g$, at max M; otherwise

$f_2 = Mg$

(b) Determine the largest value of M for which the blocks can remain at rest.

$T = Mg = f_2 = \mu_{s2}(m_1 + m_2)g$

$M_{max} = \mu_{s2}(m_1 + m_2)$

(c) Now suppose that M is large enough that the hanging block descends when the blocks are released. Assume that blocks 1 and 2 are moving as a unit (no slippage). Determine the magnitude a of their acceleration.

$Mg - T = Ma$

$T - \mu_{k2}(m_1+m_2)g = (m_1+m_2)a$

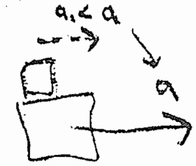
$T - f_2 = F_{NET} = m_{net}a$

$$a = \cancel{\frac{T+f_2}{M+m_1+m_2}} = \boxed{\frac{Mg - \mu_{k2}(m_1+m_2)g}{m_1+m_2+M}}$$

$Mg - \mu_{k2}(m_1+m_2)g = (M+m_1+m_2)a$

(d) Now suppose that M is large enough that as the hanging block descends, block 1 is slipping on block 2. Determine each of the following.

$a_1 < a$



i. The magnitude a_1 of the acceleration of block 1

$m_1 a_1 = \mu_{k1} m_1 g$

$a_1 = \mu_{k1} g$

ii. The magnitude a_2 of the acceleration of block 2

$T - \mu_{k2}(m_1+m_2)g - \mu_{k1}(m_1 g) = m_2 a_2$

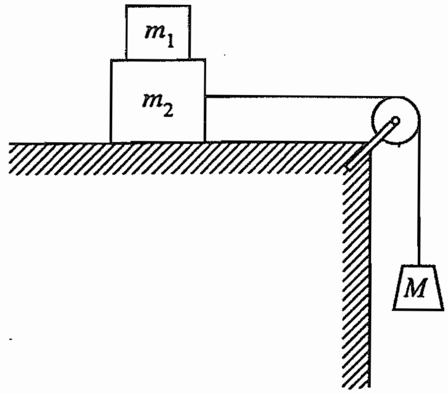
$Mg - T = Ma_2$

$$\frac{Mg - \mu_{k2}(m_1+m_2)g - \mu_{k1} m_1 g}{m_2 + M} = a_2$$

Commentary:

This is an excellent solution, showing a firm grasp of the principles involved.

Very Good Student Response: 12 points



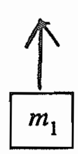
Mech. 3. Block 1 of mass m_1 is placed on block 2 of mass m_2, which is then placed on a table. A string connecting block 2 to a hanging mass M passes over a pulley attached to one end of the table, as shown above. The mass and friction of the pulley are negligible. The coefficients of friction between blocks 1 and 2 and between block 2 and the tabletop are nonzero and are given in the following table.

	Coefficient Between Blocks 1 and 2	Coefficient Between Block 2 and the Tabletop
Static	μ_{s1}	μ_{s2}
Kinetic	μ_{k1}	μ_{k2}

Express your answers in terms of the masses, coefficients of friction, and g, the acceleration due to gravity.

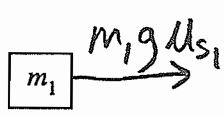
(a) Suppose that the value of M is small enough that the blocks remain at rest when released. For each of the following forces, determine the magnitude of the force and draw a vector on the block provided to indicate the direction of the force if it is nonzero.

i. The normal force N_1 exerted on block 1 by block 2

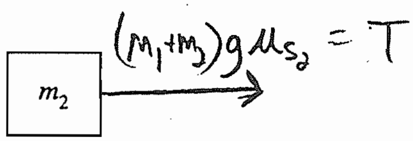


$N_1 = mg$

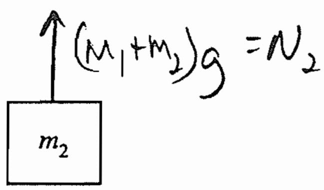
ii. The friction force f_1 exerted on block 1 by block 2



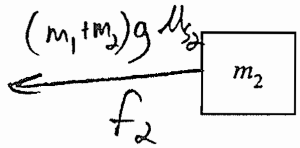
iii. The force T exerted on block 2 by the string



iv. The normal force N_2 exerted on block 2 by the tabletop



v. The friction force f_2 exerted on block 2 by the tabletop



(b) Determine the largest value of M for which the blocks can remain at rest.

$$\Sigma F = ma = 0 \qquad Mg - T = Ma = 0$$

$$m_2 a = 0 = T - (m_1+m_2)g\mu_{s_2} \qquad Mg = T$$

$$0 = Mg - (m_1+m_2)g\mu_{s_2}$$

$$(m_1+m_2)g\mu_{s_2} = Mg$$

$$\underline{M = (m_1+m_2)\mu_{s_2}}$$

(c) Now suppose that M is large enough that the hanging block descends when the blocks are released. Assume that blocks 1 and 2 are moving as a unit (no slippage). Determine the magnitude a of their acceleration.

$$\Sigma F = ma$$

$$Ma = Mg - T \qquad (m_1+m_2)a = T - (m_1+m_2)g\mu_{k_2}$$

$$T = Mg - Ma \qquad (m_1+m_2)a = M(g-a) - (m_1+m_2)g\mu_{k_2}$$

$$\boxed{a = \frac{M(g-a) - (m_1+m_2)g\mu_{k_2}}{m_1+m_2}}$$

(d) Now suppose that M is large enough that as the hanging block descends, block 1 is slipping on block 2. Determine each of the following.

i. The magnitude a_1 of the acceleration of block 1

$$\Sigma F = ma_1$$

$$m_1 a_1 = m_1 g \mu_{sk_1}$$

$$a_1 = g\mu_{sk_1}$$

ii. The magnitude a_2 of the acceleration of block 2

$$\Sigma F = m_2 a_2 \qquad Ma_2 = Mg - T$$

$$m_2 a_2 = T - (m_1+m_2)g\mu_{k_2} - m_1 g\mu_{k_1}$$

$$ma_2 = Mg - Ma_2 - (m_1+m_2)g\mu_{k_2} - m_1 g\mu_{k_1}$$

$$\boxed{a_2 = \frac{Mg - (m_1+m_2)g\mu_{k_2} - m_1 g\mu_{k_1}}{m_2 + M}}$$

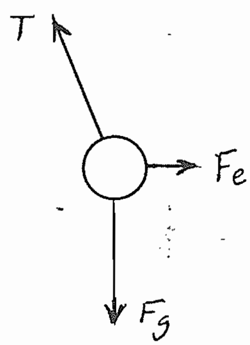
Commentary:

This student makes some mistakes in part (a) and does not completely solve for the acceleration in part (c), but shows a good deal of understanding of the physics in this problem.

A somewhat non-traditional application of the laws of electrostatics and the conditions for static equilibrium is required in this question. As such, it is a very good test of the student's grasp of these concepts. In addition, the difference between the behavior of conductors and non-conductors in an electrostatic field is tested. Many students incorrectly concluded that "same vertical height," in part (b) implied the same equilibrium angle. A straightforward application of calculus to the determination of the work done against electrostatic repulsion is needed in the last part of the question.

Distribution of points

(a) 4 points



For magnitudes of electric and gravitational forces, F_g and F_e — 1 point

For equating F_g and F_e to components of T — 1 point

$T\cos\theta = F_g = mg$

$T\sin\theta = F_e = \dfrac{kQ_AQ_B}{r^2}$

Eliminate T between these two equations and solve for Q_B.

For example from 1st equation,

$$T = \frac{(0.025\text{ kg})(9.8\text{ m/s}^2)}{\cos 20^\circ} = 0.26\text{ N}$$

Substituting into the 2nd equation,

$$(0.26\text{ N})\sin 20^\circ = \frac{(9\times10^9\text{ N}\cdot\text{m}^2/\text{C}^2)(120\times10^{-6}\text{ C})Q_B}{(1.5\text{m})^2}$$

For proper substitutions — 1 point

For the correct answer — 1 point

$Q = 1.86\times10^{-7}$ C (or 1.9×10^{-7} C)

(b) 2 points

For correct answer — 1 point

The new equilibrium angle will be less than 20° (or it decreases).

For reasonable justification that indicates charges moved on conductor so positive charge is farther apart or that indicates that F_e is smaller. — 1 point

Example:

The conductor allows charges to move. Positive charge will be on the far side of B from A and with a greater distance the electric force will be smaller.

Distribution of points

E & M 1 (continued)

(c) 3 points

Using Gauss's law

$\oint \mathbf{E} \cdot d\mathbf{A} = \dfrac{q}{\varepsilon_0}$

For evaluation of integral in equation above	1 point
For correct expression for charge enclosed	1 point

$E(2\pi r\ell) = \dfrac{\lambda\ell}{\varepsilon_0}$

$E = \dfrac{\lambda}{2\pi r\varepsilon_0} = \dfrac{0.10\times10^{-6}\ \text{C/m}}{2\pi r\left(8.85\times10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2\right)}$

For either of the two expressions above for E — 1 point

$E = \dfrac{1.8\times10^3}{\text{r}}\ \text{N/C}$

(d) 2 points

$F = qE$

For proper substitutions in equation above — 1 point

$F = \left(120\times10^{-6}\ \text{C}\right)\left(\dfrac{1.8\times10^3}{1.5}\right)\text{N/C}$

For correct answer — 1 point

$F = 0.14$ N

(e) 4 points

For expression for work, such as $W = q\Delta V$ or $\int qE\,dr$	1 point
For integral with proper limits	1 point
For the proper evaluation of integral and substitution	1 point

For example,

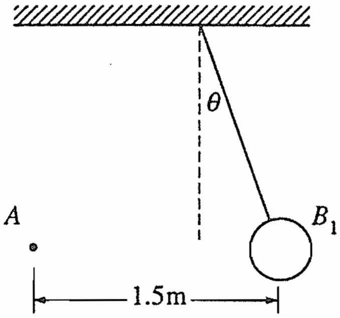
$W = \int_a^b \mathbf{F}\cdot d\mathbf{s} = -\int_a^b qE\,dr = -q\int_{1.5}^{3}\dfrac{1.8\times10^3}{r}dr$

$W = -(120\times10^{-6})\left(1.8\times10^3\right)\int_{1.5}^{0.3}\dfrac{1}{r}dr = -.216\left[\ln r\right]_{1.5}^{0.3} = -.216\left(\ln 0.3 - \ln 1.5\right)$

For the correct answer — 1 point

$W = 0.35$ J

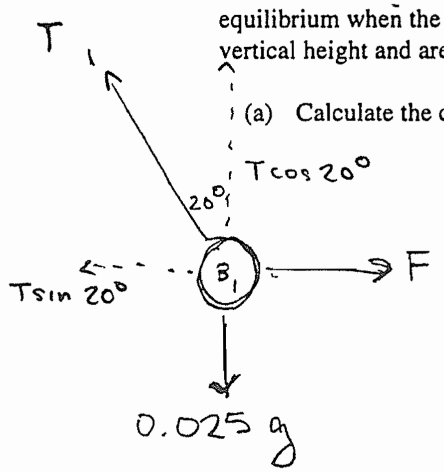
Alternately, one could find ΔV using a similar integral and then use $W = q\Delta V$, with assignment of points similar to the above to maximum of 4 points.



Note: Figure not drawn to scale.

E & M. 1. The small sphere A in the diagram above has a charge of 120 μC. The large sphere B_1 is a thin shell of nonconducting material with a net charge that is uniformly distributed over its surface. Sphere B_1 has a mass of 0.025 kg, a radius of 0.05 m, and is suspended from an uncharged, nonconducting thread. Sphere B_1 is in equilibrium when the thread makes an angle $\theta = 20°$ with the vertical. The centers of the spheres are at the same vertical height and are a horizontal distance of 1.5 m apart, as shown.

(a) Calculate the charge on sphere B_1.



Since the sphere is at equilibrium,

$$T \cos 20° = 0.025\,g$$

$$T = 0.261\,\mathrm{N}$$

$$T \sin 20° = F$$

$$0.089\,\mathrm{N} = F$$

$$F = \frac{k\,(120\,\mu C)(Q)}{1.5^2} = 480000\,Q$$

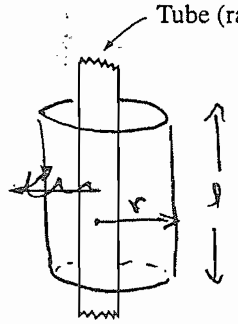
$$Q = \underline{1.86 \times 10^{-7}\ C}$$

(b) Suppose that sphere B_1 is replaced by a second suspended sphere B_2 that has the same mass, radius, and charge, but that is conducting. Equilibrium is again established when sphere A is 1.5 m from sphere B_2 and their centers are at the same vertical height. State whether the equilibrium angle θ_2 will be less than, equal to, or greater than 20°. Justify your answer.

θ_2 will be less than 20°. If B_2 is a conducting sphere, a slightly more negative charge density will be induced on the near (left) side of B_2. This will lessen F.

The sphere B_2 is now replaced by a very long, horizontal, nonconducting tube, as shown in the top view below. The tube is hollow with thin walls of radius $R = 0.20$ m and a uniform positive charge per unit length of $\lambda = +0.10\ \mu\text{C/m}$.

Tube (radius R)



Top View

(c) Use Gauss's law to show that the electric field at a perpendicular distance r from the tube is given by the expression $E = \dfrac{1.8 \times 10^3}{r}$ N/C, where $r > R$ and r is in meters.

Construct Gaussian surface, a cylinder parallel to tube and with the same center and radius r.

$\phi_{net} = EA = 2\pi r l E$. Gauss' law says that

$\phi_{net} = Q_{inside}/\varepsilon_0 = l\lambda/\varepsilon_0$

$2\pi r \cancel{l} E = \cancel{l}\lambda/\varepsilon_0$

$E = \lambda/2\pi r\varepsilon_0 = 1.0\ \mu\text{C/m} \big/ 2\pi r(8.85 \times 10^{-12}\ \text{C}^2/\text{Nm}^2) = \dfrac{1.8 \times 10^3}{r}$ N/C

(d) The small sphere A with charge 120 μC is now brought into the vicinity of the tube and is held at a distance of $r = 1.5$ m from the center of the tube. Calculate the repulsive force that the tube exerts on the sphere.

$$F = Eq$$
$$= \left(\frac{1.8 \times 10^3}{1.5\text{ m}}\right) \text{N/C} \cdot 120 \times 10^{-6}\text{ C}$$
$$= 0.144\text{ N}$$

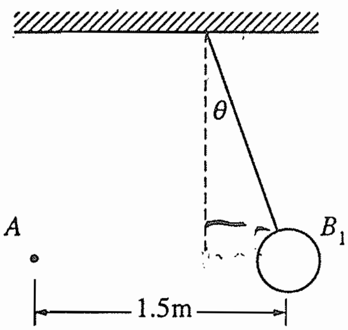
(e) Calculate the work done against the electrostatic repulsion to move sphere A toward the tube from a distance $r = 1.5$ m to a distance $r = 0.3$ m from the tube.

$$W = -\int F\,dx$$
$$= -\int_{1.5}^{0.3} \frac{0.216}{x}\,dx$$
$$= -0.216 \int_{1.5}^{0.3} \frac{dx}{x}$$
$$= 0.216 \ln \frac{1.5}{0.3}$$
$$= 0.348\text{ J}$$

Commentary:

This student gives an excellent solution, including clear figures that supplement the work shown.

Good Student Response: 10 points



Note: Figure not drawn to scale.

E & M. 1. The small sphere A in the diagram above has a charge of 120 μC. The large sphere B_1 is a thin shell of nonconducting material with a net charge that is uniformly distributed over its surface. Sphere B_1 has a mass of 0.025 kg, a radius of 0.05 m, and is suspended from an uncharged, nonconducting thread. Sphere B_1 is in equilibrium when the thread makes an angle $\theta = 20°$ with the vertical. The centers of the spheres are at the same vertical height and are a horizontal distance of 1.5 m apart, as shown.

(a) Calculate the charge on sphere B_1.

$$F = \frac{K(120E\text{-}6)\,Q_B}{1.5}\left(\frac{1}{1.5\cdot\cos\theta} - \frac{1}{1.5}\right) \qquad h = L - L\sin\theta$$

mg

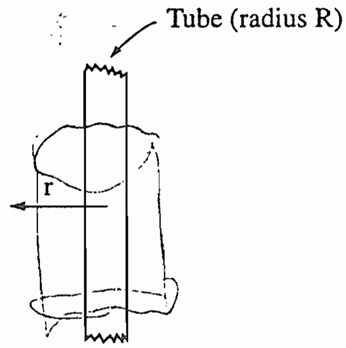
$$W = \frac{k(120E\text{-}6)\,Q_B}{}\left(\frac{1}{1.5\cos\theta} - \frac{1}{1.5}\right) = mg\cancel{L}(1-\sin\theta)$$

$$\boxed{Q_B = 1.67E\text{-}7}$$

(b) Suppose that sphere B_1 is replaced by a second suspended sphere B_2 that has the same mass, radius, and charge, but that is conducting. Equilibrium is again established when sphere A is 1.5 m from sphere B_2 and their centers are at the same vertical height. State whether the equilibrium angle θ_2 will be less than, equal to, or greater than 20°. Justify your answer.

less than. Since the sphere is conducting the sphere will polarize and will require a lesser distance to get to equilibrium

The sphere B_2 is now replaced by a very long, horizontal, nonconducting tube, as shown in the top view below. The tube is hollow with thin walls of radius $R = 0.20$ m and a uniform positive charge per unit length of $\lambda = +0.10\ \mu C/m$.



Top View

(c) Use Gauss's law to show that the electric field at a perpendicular distance r from the tube is given by the expression $E = \frac{1.8 \times 10^3}{r}$ N/C, where $r>R$ and r is in meters.

$E \oint da = \frac{Q}{\varepsilon_0}$ $Q = \lambda \ell$

$E \cdot 2\pi r \cancel{\ell} = \frac{\lambda \cancel{\ell}}{\varepsilon_0}$

$E = \frac{\lambda}{2\pi r \varepsilon_0} \approx \frac{1.8 \times 10^3}{r}$

(d) The small sphere A with charge 120 μC is now brought into the vicinity of the tube and is held at a distance of $r = 1.5$ m from the center of the tube. Calculate the repulsive force that the tube exerts on the sphere.

$$F = QE = (120\varepsilon{-6}) \cdot \frac{1.8\varepsilon 3}{1.5}$$

$$\boxed{= .144\ N}$$

(e) Calculate the work done against the electrostatic repulsion to move sphere A toward the tube from a distance $r = 1.5$ m to a distance $r = 0.3$ m from the tube.

$$\int_{1.5}^{.3} \frac{1.8\varepsilon 3 \cdot (120\varepsilon{-6})}{r}\, dr$$

$$= (1.8\varepsilon 3)(120\varepsilon{-6}) \ln\left(\frac{.3}{1.5}\right)$$

$$\boxed{= -.348\ J}$$

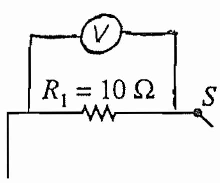
Commentary:

This student starts off poorly with the answer to part (a), which indicates the same expression as a force and as work, and also appears to cancel out an L that appears only on one side of an equation. But the student gets back on track with the remainder of the problem.

This question deals with very traditional RL and RC circuits and the behavior over time of the current and voltage in such circuits. In spite of the fact that both these circuits are analyzed in great detail in the typical E & M course, a number of students had difficulty with the last part of the problem that requires only an application, but not a solution, of Kirchhoff's loop rule to this specific circuit. The mean score on this problem was relatively high, indicating that most students understand these fundamental types of circuits well.

Distribution of points

(a) 2 points



For correct placement of voltmeter — 2 points

(b) 3 points

For correct application of Ohm's law — 1 point

$$I = \frac{\mathcal{E}}{R_1 + R_2} = \frac{20\text{ V}}{30\ \Omega}$$

For correct value of current — 1 point

$$I = \frac{2}{3}\text{ A}$$

For correct value of voltage across R_1 — 1 point

$$V_1 = IR = \frac{2}{3}\text{ A} \times 10\ \Omega = 6.67\text{ V}$$

(Alternate solution using voltage divider) — *(Alternate points)*

For voltage divider equation — *1 point*

$$V = \frac{R_1}{R_1 + R_2}\mathcal{E}$$

For correct substitution — *1 point*

$$V = \frac{10\ \Omega}{10\ \Omega + 20\ \Omega} \times 20\text{ V}$$

For correct answer — *1 point*

$V = 6.67\text{ V}$

(c)

i. 2 points

For correct answer — 2 points

$V = 0$

(1 point awarded for stating that no current flows)

Distribution of points

E & M 2 (continued)

(c) (continued)

ii. 1 point

$Q = CV$

For correct substitutions and answer — 1 point

$Q = 15\,\mu\text{F} \times 20\,\text{V} = 300\,\mu\text{C}$

(d) 2 points

For correct answer — 2 points

$V = 0$

(1 point awarded for no current or realization of new initial conditions)

(e)

i. 2 points

For correct application of Ohm's law and answer — 2 points

$$I = \frac{\mathcal{E}}{R_1 + R_2} = \frac{20\ \text{V}}{30\,\Omega} = \frac{2}{3}\,\text{A}$$

(1 point awarded for $\dfrac{20\ \text{V}}{10\,\Omega}$)

ii. 1 point

For correct substitution in energy equation and correct answer — 1 point

$$U_l = \frac{1}{2}LI^2 = \frac{1}{2}(2\ \text{H})\left(\frac{2}{3}\ \text{A}\right)^2 = 0.444\ \text{J}$$

(1 point also awarded if incorrect current in (e)i. (except zero) was substituted and answer was consistent with this current.)

(f) 2 points

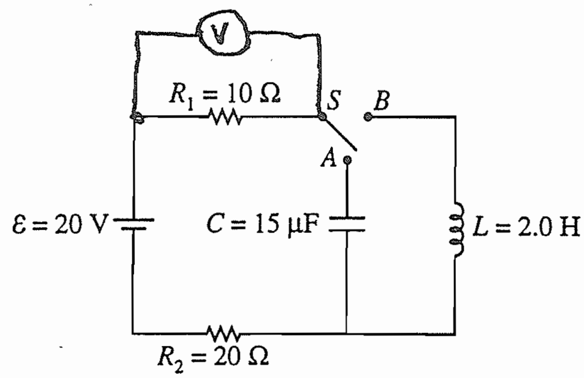
For correct equation — 2 points

$$\mathcal{E} - I(R_1 + R_2) - L\frac{dI}{dt} = 0$$

(1 point only awarded if one sign incorrect)

One point was subtracted from the final score for two or more wrong or absent units for parts where the answer was given, except where the answer was zero, in which case units were not counted.

Excellent Student Response: 15 points



E & M. 2. In the circuit shown above, the switch S is initially in the open position shown, and the capacitor is uncharged. A voltmeter (not shown) is used to measure the correct potential difference across resistor R_1.

(a) On the circuit diagram above, draw the voltmeter with the proper connections for correctly measuring the potential difference across resistor R_1.

(b) At time $t = 0$, the switch is moved to position A. Determine the voltmeter reading for the time immediately after $t = 0$.

the capacitor is like a short circuit so,

$$V = \frac{10}{10+20} \cdot 20 \approx 6.7 \text{ Volts}$$

(c) After a long time, a measurement of potential difference across R_1 is again taken. Determine for this later time each of the following.

i. The voltmeter reading

the capacitor is like an open circuit so,
0 volts

ii. The charge on the capacitor

$$Q = VC = (20 \cdot 15)\mu C = 300\, \mu C$$

(d) At a still later time $t = T$, the switch S is moved to position B. Determine the voltmeter reading for the time immediately after $t = T$.

the inductor is like an open circuit so,

0 volts

(e) A long time after $t = T$, the current in R_1 reaches a constant final value I_f.

i. Determine I_f.

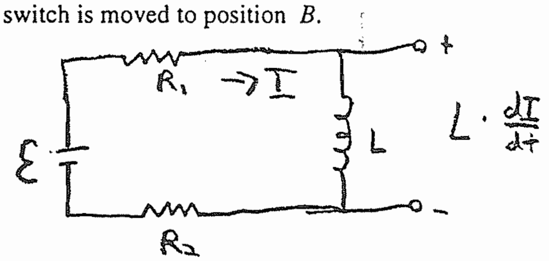
now inductor is like short circuit so,

$$I_f = \frac{20\text{V}}{(10+20)\Omega} \approx .67\text{ A}$$

ii. Determine the final energy stored in the inductor.

$$E = \frac{1}{2} L I_f^2 \approx .45\text{ J}$$

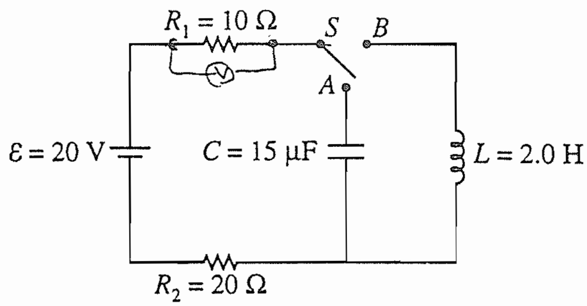
(f) Write, but do not solve, a differential equation for the current in resistor R_1 as a function of time t after the switch is moved to position B.



$$\Rightarrow I \cdot R_1 + L \cdot \frac{dI}{dt} + I \cdot R_2 = \mathcal{E} \Rightarrow \frac{dI}{dt} + \frac{(R_1+R_2)}{L} I - \frac{\mathcal{E}}{L} = 0$$

Commentary:

This student shows good understanding of the behavior of the two basic circuits in this problem. The tendency shown to substitute numbers without units into a final equation, with no prior steps, could be a liability in a more complex solution. Here, however, it is easy to follow the student's work.



E & M. 2. In the circuit shown above, the switch S is initially in the open position shown, and the capacitor is uncharged. A voltmeter (not shown) is used to measure the correct potential difference across resistor R_1.

(a) On the circuit diagram above, draw the voltmeter with the proper connections for correctly measuring the potential difference across resistor R_1.

(b) At time $t = 0$, the switch is moved to position A. Determine the voltmeter reading for the time immediately after $t = 0$.

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

$20 = V_{R_2} + \frac{q}{C} + V_{R_1}$

$20 = (10+20)i$

$i = 2/3$ A

$V_{R_1} = (10)(\frac{2}{3}) = 6.67$ V

(c) After a long time, a measurement of potential difference across R_1 is again taken. Determine for this later time each of the following.

i. The voltmeter reading

$V = 0$ V b/c $i \to 0$ in the circuit as C is charged

ii. The charge on the capacitor

$V_C = 20$V

$C = 15\times10^{-6} = \frac{q}{20}$

$q = 3\times10^{-4}$ C

(d) At a still later time $t = T$, the switch S is moved to position B. Determine the voltmeter reading for the time immediately after $t = T$.

$V = 0V$

inductors only induce an $\mathcal{E}$ when the current is changing

(e) A long time after $t = T$, the current in R_1 reaches a constant final value I_f.

i. Determine I_f.

$20 = I_f(10 + 20)$

$I_f = .67A$

ii. Determine the final energy stored in the inductor.

$U_L = \frac{1}{2} L I_f^2$

$= \frac{1}{2}(2)(\frac{2}{3})^2$

$U_L = \frac{4}{9} J$

(f) Write, but do not solve, a differential equation for the current in resistor R_1 as a function of time t after the switch is moved to position B.

i_1 through R_1 gradually increases as t increases

Commentary:

This student shows good understanding of the limiting cases for these circuits, but fails to write the equation governing the time-dependent behavior.

This question is a modification of a very standard problem involving the induced emf produced by a moving conductor that forms part of a closed circuit. The somewhat unusual aspect of the question is that the conductor moves under the influence of both magnetic and gravitational forces. Lenz's law then requires that the conductor reach a terminal velocity, and that terminal velocity and its dependence on various factors is a focus of much of the question. The typical student had difficulty with part (d). The last part of the question really tests the student's understanding of the problem, particularly since the correct answer is somewhat counterintuitive.

Distribution of points

(a) 4 points

Using Newton's 2nd law along the ramp,
$F_g \sin\theta - F_m = ma$, where F_g = force of gravity, and F_m = magnetic force
At constant speed, $a = 0$, so $F_g \sin\theta - F_m = 0$

For the following expression for F_m — 1 point
$F_m = F_g \sin\theta$

For substituting $F_g = mg$ — 1 point
$F_m = mg \sin\theta$

For substituting $F_m = I\ell B$ — 1 point
$I\ell B = mg \sin\theta$

For correct answer — 1 point
$$I = \frac{mg\sin\theta}{\ell B}$$

(b) 4 points

$$|\mathcal{E}| = \left|-\frac{d\phi_M}{dt}\right|$$

For correct expression for ϕ_M — 1 point
$\phi_M = B\ell x$
For the time deriviative of ϕ_M — 1 point
$$\frac{d\phi_M}{dt} = B\ell\upsilon$$
For correct use of Ohm's law to find current — 1 point
$\mathcal{E} = IR$
$$I = \frac{\mathcal{E}}{R} = \frac{B\ell\upsilon}{R}$$

For equating this expression to the expression for I from part (a) and solving for υ — 1 point
$$\frac{B\ell\upsilon}{R} = \frac{mg\sin\theta}{B\ell}$$
$$\upsilon = \frac{mgR\sin\theta}{B^2\ell^2}$$

E & M 3 (continued)

Distribution of points

(c) 2 points

For correct expression for power — 1 point

$P = I^2 R$

For correction substitution of the expression for I from part (a) — 1 point

$$P = \frac{(m^2 g^2 \sin^2\theta)R}{B^2\ell^2}$$

(d) 3 points

For either of the following two expressions — 1 point

$$m\frac{dv}{dt} = mg\sin\theta - I\ell B$$

$$\frac{dv}{dt} = g\sin\theta - \frac{B^2\ell^2 v}{mR}$$

For rearranging terms in either expression to set up intergral — 1 point

For example,

$$\frac{dv}{g\sin\theta - \dfrac{B^2\ell^2 v}{mR}} = dt$$

For integrating this expression, and applying $v(0) = 0$ to get answer — 1 point

$$v(t) = \frac{mRg\sin\theta}{B^2\ell^2}\left[1 - \exp\left(-\frac{B^2\ell^2 t}{mR}\right)\right]$$

(e) 2 points

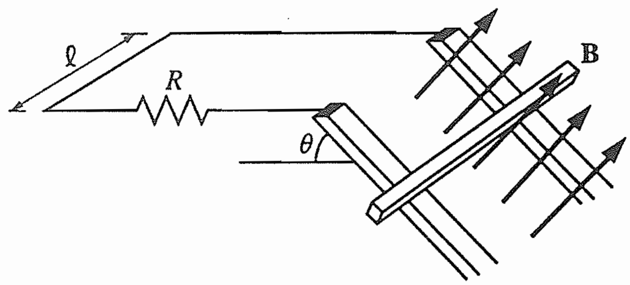
For correct answer — 1 point

Yes, the final speed of the bar decreases

For any reasonable justification — 1 point

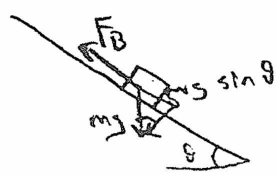
For example;

Since the two resistors are in parallel across the emf in the bar, the new effective resistance is $\dfrac{R}{2}$. And since $v = \dfrac{mgR\sin\theta}{B^2\ell^2}$ from part (b), then if R decreases, the speed decreases.



E & M. 3. A conducting bar of mass m is placed on two long conducting rails a distance ℓ apart. The rails are inclined at an angle θ with respect to the horizontal, as shown above, and the bar is able to slide on the rails with negligible friction. The bar and rails are in a uniform and constant magnetic field of magnitude B oriented perpendicular to the incline. A resistor of resistance R connects the upper ends of the rails and completes the circuit as shown. The bar is released from rest at the top of the incline. Express your answers to parts (a) through (d) in terms of m, ℓ, θ, B, R, and g.

(a) Determine the current in the circuit when the bar has reached a constant final speed.



$$a = 0$$

$$F_{net} = 0$$

$$F_B = mg \sin\theta$$

$$I\ell B = mg \sin\theta$$

$$I = \frac{mg \sin\theta}{\ell B}$$

(b) Determine the constant final speed of the bar.

$$\mathcal{E}_{induced} = IR = \frac{d\phi}{dt}$$

$$= \frac{B\,dA}{dt} = \frac{B\ell\,dx}{dt} = B\ell v$$

$$v = \frac{IR}{B\ell} = \frac{mg \sin\theta\, R}{B^2\ell^2}$$

(c) Determine the rate at which energy is being dissipated in the circuit when the bar has reached its constant final speed.

$$P = I\mathcal{E} = I^2R$$
$$= \left(\frac{mg\sin\theta}{B\ell}\right)^2 R$$

(d) Express the speed of the bar as a function of time t from the time it is released at $t = 0$.

$$F_{net} = mg\sin\theta - F_B \qquad F_B = I\ell B$$
$$= mg\sin\theta - \frac{I}{R}v(B\ell)^2 \qquad I = \frac{\mathcal{E}}{R} = \frac{B\ell v}{R}$$
$$a = \frac{F_{net}}{m} = g\sin\theta - \frac{Iv(B\ell)^2}{mR} \qquad F_B = \frac{I}{R}v(B\ell)^2$$
$$dv = g\sin\theta - \frac{I(B\ell)^2}{mR}v\,dt$$

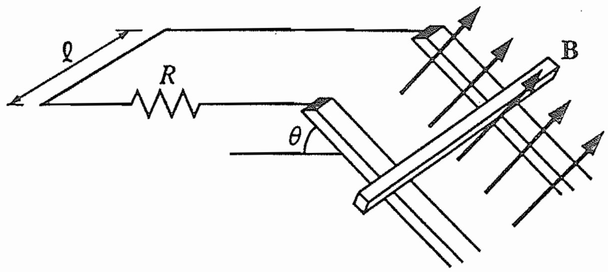
(e) Suppose that the experiment is performed again, this time with a second identical resistor connecting the rails at the bottom of the incline. Will this affect the final speed attained by the bar, and if so, how? Justify your answer.

~~[illegible]~~
~~[illegible] a second~~
~~Y[illegible]~~

Yes - the resistors are connected in parallel, and experience the same emf, effectively doubling the current across the bar and reducing its ~~maximum~~ final speed.

Commentary:
This student only loses credit for part (d), where the variables are not properly separated for integration and a final answer is not obtained.

Good Student Response: 11 points



E & M. 3. A conducting bar of mass m is placed on two long conducting rails a distance ℓ apart. The rails are inclined at an angle θ with respect to the horizontal, as shown above, and the bar is able to slide on the rails with negligible friction. The bar and rails are in a uniform and constant magnetic field of magnitude B oriented perpendicular to the incline. A resistor of resistance R connects the upper ends of the rails and completes the circuit as shown. The bar is released from rest at the top of the incline. Express your answers to parts (a) through (d) in terms of m, ℓ, θ, B, R, and g.

(a) Determine the current in the circuit when the bar has reached a constant final speed.

$$-\Sigma F = ma$$

$$mg \sin\theta - i\ell B = 0$$

$$\boxed{i = \frac{mg \sin\theta}{\ell B}}$$

(b) Determine the constant final speed of the bar.

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

$$IR = -v\ell B$$

$$\frac{mg\sin\theta}{\ell B} R = v\ell B$$

$$\frac{mg \sin\theta\, R}{\ell^2 B^2} = v$$

(c) Determine the rate at which energy is being dissipated in the circuit when the bar has reached its constant final speed.

$$P = I^2 R$$

$$\left(\frac{mg\sin\theta}{lB}\right)^2 R$$

$$P = \frac{m^2 g^2 \sin^2\theta}{l^2 B^2} R$$

(d) Express the speed of the bar as a function of time t from the time it is released at $t = 0$.

$$mg\sin\theta - ilB = m\frac{dv}{dt} \qquad \Phi_m = \oint B \cdot dl \qquad ds = v\,dt$$

$$(mg\sin\theta - ilB)\,dt = m\,dv \qquad \Phi_m = \int_0^v B\,l\,ds$$

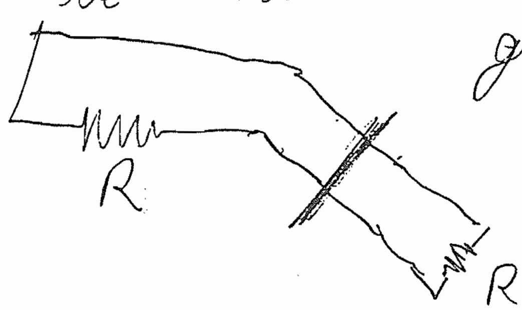
$$v\,dt$$

$$mg\sin\theta - \int_0^t ilB\,dt = \int_0^v m\,dv$$

$$= mv$$

(e) Suppose that the experiment is performed again, this time with a second identical resistor connecting the rails at the bottom of the incline. Will this affect the final speed attained by the bar, and if so, how? Justify your answer.

Yes it would create a parallel circuit. Thus th overall resistance would be lower and th current greater.



Commentary:

This student does not correctly perform the integration in part (d). Also, there is no indication of how the speed changes in part (e); there must be a complete answer to justify in order to receive credit for the justification.

Chapter VI Statistical Information

- Section II Scores
- How AP Grades are Determined
- Grade Distributions
- Section I Scores and AP Grades
- College Comparability Studies
- Reminders for all Grade Report Recipients
- Reporting AP Grades
- Purpose of AP Grades

Table 4.1 — Section II Scores

The following tables show the score distributions for AP candidates on each free-response question from the 1998 Physics exams.

Physics B

	Question 1		Question 2		Question 3		Question 4	
Score	Number of Students	% At Score	Number of Students	% At Score	Number of Students	% At Score	Number of Students	% At Score
15	1,843	7.6	154	0.6				
14	573	2.4	643	2.7				
13	714	3.0	1,083	4.5				
12	1,260	5.2	813	3.4				
11	951	3.9	675	2.8				
10	1,293	5.3	774	3.2	4,788	19.9	1,286	5.3
9	1,322	5.5	1,026	4.3	3,394	14.1	487	2.0
8	1,370	5.7	1,062	4.4	2,643	11.0	2,589	10.7
7	1,755	7.3	1,335	5.5	1,601	6.6	1,738	7.2
6	1,773	7.4	2,261	9.4	1,098	4.6	1,862	7.7
5	1,943	8.1	3,303	13.7	951	3.9	2,817	11.7
4	2,247	9.3	3,155	13.1	1,035	4.3	2,717	11.3
3	1,974	8.2	2,906	12.1	1,151	4.8	3,595	14.9
2	1,561	6.5	2,075	8.6	1,434	6.0	3,498	14.5
1	1,723	7.2	1,097	4.6	1,723	7.2	2,397	9.9
0	1,207	5.0	718	3.0	1,635	6.8	674	2.8
No response	586	2.4	1,015	4.2	2,642	11.0	435	1.8

	Question 5		Question 6		Question 7		Question 8	
Score	Number of Students	% At Score	Number of Students	% At Score	Number of Students	% At Score	Number of Students	% At Score
10	829	3.4	144	0.6	201	0.8	1,637	6.8
9	2,637	10.9	420	1.7	331	1.4	1,111	4.6
8	2,394	9.9	1,192	4.9	396	1.6	1,345	5.6
7	3,419	14.2	2,907	12.1	395	1.6	1,377	5.7
6	2,564	10.6	2,670	11.1	865	3.6	1,530	6.3
5	2,051	8.5	2,785	11.6	1,266	5.3	1,997	8.3
4	1,805	7.5	2,952	12.2	903	3.7	2,426	10.1
3	1,824	7.6	2,634	10.9	1,442	6.0	2,476	10.3
2	1,426	5.9	2,614	10.8	2,978	12.4	2,922	12.1
1	1,380	5.7	2,163	9.0	2,190	9.1	1,981	8.2
0	1,742	7.2	2,508	10.4	7,310	30.3	1,930	8.0
No response	2,024	8.4	1,106	4.6	5,818	24.1	3,363	14.0

	Question 1	Question 2	Question 3	Question 4	Question 5	Question 6	Question 7	Question 8
Total Candidates	24,095	24,095	24,095	24,095	24,095	24,095	24,095	24,095
Mean	6.59	5.56	5.57	4.42	4.88	3.82	1.60	3.77
Standard Deviation	4.48	3.76	3.81	2.72	3.15	2.61	2.36	3.18
Mean as % of Maximum Score	44	37	56	44	49	38	16	38

Physics C: Mechanics

Score	Question 1 Number of Students	Question 1 % At Score	Question 2 Number of Students	Question 2 % At Score	Question 3 Number of Students	Question 3 % At Score
15	1,353	10.3	119	0.9	66	0.5
14	641	4.9	119	0.9	92	0.7
13	1,284	9.8	176	1.3	254	1.9
12	789	6.0	255	1.9	372	2.8
11	839	6.4	330	2.5	563	4.3
10	906	6.9	484	3.7	816	6.2
9	1,260	9.6	903	6.9	1,162	8.9
8	1,367	10.4	1,374	10.5	1,347	10.3
7	1,243	9.5	1,560	11.9	1,155	8.8
6	1,049	8.0	1,140	8.7	1,203	9.2
5	795	6.1	1,098	8.4	853	6.5
4	599	4.6	933	7.1	903	6.9
3	362	2.8	811	6.2	1,397	10.7
2	227	1.7	1,127	8.6	1,700	13.0
1	182	1.4	523	4.0	606	4.6
0	121	0.9	1,839	14.1	259	2.0
No response	71	0.5	297	2.3	340	2.6

Physics C: E & M

Score	Question 1 Number of Students	Question 1 % At Score	Question 2 Number of Students	Question 2 % At Score	Question 3 Number of Students	Question 3 % At Score
15	167	2.6	441	6.8	25	0.4
14	127	2.0	211	3.3	32	0.5
13	380	5.9	650	10.1	83	1.3
12	287	4.4	291	4.5	123	1.9
11	328	5.1	289	4.5	170	2.6
10	311	4.8	297	4.6	226	3.5
9	338	5.2	354	5.5	178	2.8
8	350	5.4	535	8.3	162	2.5
7	348	5.4	339	5.3	178	2.8
6	381	5.9	412	6.4	333	5.2
5	374	5.8	486	7.5	356	5.5
4	476	7.4	386	6.0	577	8.9
3	487	7.5	433	6.7	519	8.0
2	530	8.2	781	12.1	535	8.3
1	533	8.3	122	1.9	786	12.2
0	850	13.2	250	3.9	1,274	19.7
No response	188	2.9	178	2.8	898	13.9

	Physics C: Mechanics Question 1	Physics C: Mechanics Question 2	Physics C: Mechanics Question 3	Physics C: E & M Question 1	Physics C: E & M Question 2	Physics C: E & M Question 3
Total Candidates	13,088	13,088	13,088	6,455	6,455	6,455
Mean	9.10	5.24	5.88	5.70	7.27	3.28
Standard Deviation	3.82	3.70	3.52	4.55	4.58	3.71
Mean as % of Maximum Score	61	35	39	38	48	22

How AP Grades are Determined

On the Physics B Exam, students could have received anywhere between 0 and 70 points for Section I, and 0 and 90 points for Section II. On either part of the Physics C Exam, they could have earned between 0 and 35 points for Section I*, and up to 45 points for Section II. However, these raw scores are not released to the student, school, or college. Instead, they are converted to grades on an AP 5-point scale, and it is these grades that are reported. This conversion involves a number of steps, which are detailed on the Scoring Worksheets on the next three pages:

1. **The multiple-choice score is calculated.** To adjust for random guessing, a fraction of the number of wrong answers is subtracted from the number of right answers. This fraction is 1/4 for five-choice questions (as on the Physics exams), so that the expected score from random guessing will be zero.
2. **The free-response and multiple choice scores are each weighted.** When either of the sections includes two or more parts, those parts are weighted according to the value assigned to them by the Development Committee. This allows the committee to place more importance on certain skills to correspond to their emphasis in the corresponding college curriculum.
3. **A composite score is calculated.** Weighting also comes into play when looking at the multiple-choice section in comparison to the free-response section. In consultation with experts from the College Board and ETS, the Physics committee decided that each section should contribute an equal amount to the total score. For Physics B, the maximum composite score was 180, with each section contributing up to 90 points. The Scoring Worksheet details the process of converting section scores to composite scores for this exam. For each Physics C exam, the maximum composite score was 90, with each section contributing up to 45 points.
4. **AP grades are calculated.** The Chief Faculty Consultant sets the four cut points that divide the composite scores into groups. A variety of information is available to help the CFC determine the score ranges into which the exam grades should fall:
   - Distributions of scores on each portion of the multiple-choice and free-response sections of the exam are provided, along with totals for each section and the composite score total.
   - With these tables and special statistical tables presenting grade distributions from previous years, the CFC can compare the exam at hand to results of other years.
   - For each composite score, a roster summarizes student performance on all sections of the exam.
   - Finally, on the basis of professional judgment regarding the quality of performance represented by the achieved scores, the CFC determines the candidates' final AP grades.

   See Table 4.3 for the 1998 AP Physics Exams grade distributions.

If you're interested in more detailed information about this process, please see the "Technical Corner" of our website: www.collegeboard.org/ap. There you'll also find information about how the AP Exams are developed, how validity and reliability studies are conducted, and other nuts-and-bolts data on all AP subjects.

* Question 23 on the Physics C: Mechanics exam was not scored, and so students could only have earned up to 34 points on that part.

Table 4.2 — Scoring Worksheet — AP Physics B

Section I: Multiple Choice

[________ − (1/4 × ________)] × 1.2857 = ________ = ________

Number correct (out of 70); Number wrong; Multiple-Choice Score (Do not round. If less than zero, enter zero.); Weighted Section I Score

Section II: Free Response

Question 1	________ (out of 15)	× 1.000 =	________
Question 2	________ (out of 15)	× 1.000 =	________
Question 3	________ (out of 10)	× 1.000 =	________
Question 4	________ (out of 10)	× 1.000 =	________
Question 5	________ (out of 10)	× 1.000 =	________
Question 6	________ (out of 10)	× 1.000 =	________
Question 7	________ (out of 10)	× 1.000 =	________
Question 8	________ (out of 10)	× 1.000 =	________
		Sum =	________

Weighted Section II Score

AP Grade Conversion Chart Physics B

Composite Score Range*	AP Grade
106-180	5
83-105	4
54-82	3
40-53	2
0-39	1

*The candidates' scores are weighted according to formulas determined in advance each year by the Development Committee to yield raw composite scores; the Chief Faculty Consultant is responsible for converting composite scores to the 5-point AP scale.

Composite Score

________ + ________ = ________

Weighted Section I Score; Weighted Section II Score; Composite Score (Round to nearest whole number.)

Table 4.2 — Scoring Worksheet — AP Physics C: Mechanics

Section I: Multiple Choice

$$\left[\underset{\substack{\text{Number correct}\\ \text{(out of 34)}}}{\underline{\qquad\qquad}} - \left(1/4 \times \underset{\text{Number wrong}}{\underline{\qquad\qquad}}\right)\right] \times 1.3235 = \underset{\substack{\text{Multiple-Choice}\\ \text{Score}\\ \text{(Do not round.)}}}{\underline{\qquad\qquad}} = \underset{\substack{\text{Weighted}\\ \text{Section I}\\ \text{Score}}}{\underline{\qquad\qquad}}$$

Section II: Free Response

Question 1 ________ (out of 15) × 1.000 = ________

Question 2 ________ (out of 15) × 1.000 = ________

Question 3 ________ (out of 15) × 1.000 = ________

Sum = ________
Weighted Section II Score (Do not round)

Composite Score

________ + ________ = ________
Weighted Section I Score + Weighted Section II Score = Composite Score (Round to nearest whole number.)

AP Grade Conversion Chart Physics C: Mechanics

Composite Score Range*	AP Grade
55-90	5
43-54	4
32-42	3
21-31	2
0-20	1

*The candidates' scores are weighted according to formulas determined in advance each year by the Development Committee to yield raw composite scores; the Chief Faculty Consultant is responsible for converting composite scores to the 5-point AP scale.

Table 4.2 — Scoring Worksheet — AP Physics C: Electricity & Magnetism

Section I: Multiple Choice

[________ − (1/4 × ________)] × 1.2857 = ________ = ________

Number correct (out of 35) — Number wrong — Multiple-Choice Score (Do not round.) — Weighted Section I Score

Section II: Free Response

Question 1 ________ (out of 15) × 1.000 = ________ (Do not round)

Question 2 ________ (out of 15) × 1.000 = ________ (Do not round)

Question 3 ________ (out of 15) × 1.000 = ________ (Do not round)

Sum = ________

Weighted Section II Score (Do not round.)

Composite Score

________ + ________ = ________

Weighted Section I Score + Weighted Section II Score = Composite Score (Round to nearest whole number.)

AP Grade Conversion Chart Physics C: E & M

Composite Score Range*	AP Grade
49-90	5
35-48	4
26-34	3
15-25	2
0-14	1

*The candidates' scores are weighted according to formulas determined in advance each year by the Development Committee to yield raw composite scores; the Chief Faculty Consultant is responsible for converting composite scores to the 5-point AP scale.

Table 4.3 — Grade Distributions

Physics B

Nearly two thirds of the AP students who took this exam earned a qualifying grade of 3 or above.

	Examination Grade	Number of Students	Percent at Grade
Extremely well qualified	5	3825	15.9
Well qualified	4	4559	18.9
Qualified	3	7583	31.5
Possibly qualified	2	3440	14.3
No recommendation	1	4688	19.5
Total Number of Students		24,095	
Mean Grade		2.97	
Standard Deviation		1.32	

Physics C — Mechanics

More than two thirds of the AP students who took this exam earned a qualifying grade of 3, or above.

	Examination Grade	Number of Students	Percent at Grade
Extremely well qualified	5	3340	25.5
Well qualified	4	2989	22.8
Qualified	3	2595	19.8
Possibly qualified	2	2111	16.1
No recommendation	1	2053	15.7
Total Number of Students		13,088	
Mean Grade		3.26	
Standard Deviation		1.40	

Physics C — Electricity & Magnetism

Nearly two thirds of the AP students who took this exam earned a qualifying grade of 3, or above.

	Examination Grade	Number of Students	Percent at Grade
Extremely well qualified	5	1644	25.5
Well qualified	4	1499	23.2
Qualified	3	1055	16.3
Possibly qualified	2	1344	20.8
No recommendation	1	913	14.1
Total Number of Students		6,455	
Mean Grade		3.25	
Standard Deviation		1.40	

Table 4.4 — Section I Scores and AP Grades

The following tables give the probabilities that a student would receive a particular grade on each of the 1998 AP Physics Exams given that student's score on the multiple-choice section of that exam.

Physics B

Multiple-Choice Score	AP Grade					Total
	1	2	3	4	5	
41 to 70	0.0%	0.0%	0.9%	13.4%	85.7%	14.4%
32 to 40	0.0%	0.2%	19.1%	62.6%	18.2%	19.2%
21 to 31	1.1%	11.4%	71.7%	15.6%	0.1%	31.7%
16 to 20	18.4%	49.9%	31.6%	0.1%	0.0%	13.9%
0 to 15	79.6%	17.8%	2.6%	0.0%	0.0%	20.8%
Total	19.5%	14.3%	31.5%	18.9%	15.9%	100.0%

Physics C: Mechanics

Multiple-Choice Score	AP Grade					Total
	1	2	3	4	5	
23 to 34	0.0%	0.0%	0.3%	11.6%	88.0%	23.7%
17 to 22	0.0%	0.6%	16.6%	63.6%	19.3%	24.0%
13 to 16	0.1%	12.8%	59.7%	27.2%	0.3%	16.7%
8 to 12	10.3%	56.9%	31.3%	1.5%	0.0%	18.0%
0 to 7	78.3%	20.6%	1.2%	0.0%	0.0%	17.7%
Total	15.7%	16.1%	19.8%	22.8%	25.5%	100.0%

Physics C: Electricity & Magnetism

Multiple-Choice Score	AP Grade					Total
	1	2	3	4	5	
21 to 35	0.0%	0.0%	0.6%	13.9%	85.4%	24.1%
16 to 20	0.0%	1.7%	17.4%	60.0%	20.9%	22.3%
13 to 15	0.0%	21.1%	43.6%	33.8%	1.5%	15.6%
8 to 12	10.0%	60.8%	23.6%	5.4%	0.1%	22.5%
0 to 7	76.6%	22.2%	1.2%	0.0%	0.0%	15.5%
Total	14.1%	20.8%	16.3%	23.2%	25.5%	100.0%

College Comparability Studies

The Advanced Placement Program has conducted college grade comparability studies in various AP subjects. These studies have compared the performance of AP Exam candidates with that of college students in related courses who have taken the AP Exam at the end of their course. In general, these studies indicate that the lowest AP 5 is equivalent to the average A student in college, the lowest AP 4 equivalent to the average B student, and the lowest AP 3 equivalent to the average C student.

AP Grade	Average College Grade
5	
	A
4	
	B
3	
	C
2	
	D
1	

Other studies conducted by colleges and universities indicate that AP students generally receive higher grades in advanced courses than do the students who have taken the regular freshman-level courses at the institution. Each college is encouraged to undertake such studies in order to establish appropriate policy for the acceptance of AP grades. Data for these studies are readily available as large percentages of AP students successfully handle the associated course work. Some institutions have found that until these studies are undertaken, placing students into advanced classes but allowing them to transfer to a lower-level course if necessary, is a desirable educational strategy.

Reminders for All Grade Report Recipients

AP Examinations are designed to provide accurate assessments of achievement. However, any examination has limitations, especially when used for purposes other than those intended. Presented here are some suggestions for teachers to aid in the use and interpretation of AP grades.

- AP Examinations are developed and evaluated independently of each other. They are linked only by common purpose, format, and method of reporting results. Therefore, comparisons should not be made between grades on different AP Examinations. An AP grade in one subject may not have the same meaning as the same AP grade in another subject, just as national and college standards vary from one discipline to another.
- AP grades are not exactly comparable to college course grades. However, the AP Program conducts research studies every few years in each AP subject to ensure that the AP grading standards are comparable to those used in colleges with similar courses.
- The confidentiality of candidate grade reports should be recognized and maintained. All individuals who have access to AP grades should be aware of the confidential nature of the grades and agree to maintain their security. In addition, school districts and states should not release data about high school performance without the school's permission.
- AP Examinations are not designed as instruments for teacher or school evaluation. A large number of factors influence AP Exam performance in a particular course or school in any given year. As a result, differences in AP Exam performance should be carefully studied before being attributed to the teacher or school.
- Where evaluation of AP students, teachers, or courses is desired, local evaluation models should be developed. An important aspect of any evaluation model is the use of an appropriate method of comparison or frame of reference to account for yearly changes in student composition and ability, as well as local differences in resources, educational methods, and socioeconomic factors.

- The "Report to AP Teachers" can be a useful diagnostic tool in reviewing course results. This report identifies areas of strength and weakness for each AP course. This information may also help to guide your students in identifying their own strengths and weaknesses in preparation for future study. (See right for information on how to obtain this report.)
- Many factors can influence course results. AP Exam performance may be due to the degree of agreement between your course and the course defined in the relevant AP Course Description, use of different instructional methods, differences in emphasis or preparation on particular parts of the examination, differences in pre-AP curriculum, or differences in student background and preparation in comparison with the national group.

Reporting AP Grades

The results of AP Examinations are disseminated in several ways to candidates, their secondary schools, and the colleges they select.

- College and candidate grade reports contain a cumulative record of all grades earned by the candidate on AP Exams during the current or previous years. These reports are sent in early July. (School grade reports are sent shortly thereafter.)
- Group results for AP Examinations are available to AP teachers whenever five or more candidates at a school have taken a particular AP Exam. This "Report to AP Teachers" provides useful information comparing local candidate performance with that of the total group of candidates taking an exam, as well as details on different subsections of the exam.

Several other reports produced by the AP Program provide summary information on AP Examinations.

- State and National Reports show the distribution of grades obtained on each AP Exam for all candidates and for subsets of candidates broken down by sex and by ethnic group.
- The Program also produces a one-page summary of AP grade distributions for all exams in a given year.

For information on any of the above, please call AP Services at (609) 771-7300 or contact them via e-mail at apexams@ets.org.

Purpose of AP Grades

AP grades are intended to allow participating colleges and universities to award college credit, advanced placement, or both to qualified students. In general, an AP grade of 3 or higher indicates sufficient mastery of course content to allow placement in the succeeding college course, or credit for and exemption from a college course comparable to the AP course. Credit and placement policies are determined by each college or university, however, and students should be urged to contact their colleges directly to ask for specific Advanced Placement policies in writing.

Appendix AP Publications and Videos

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

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

You can order many items online through the AP Aisle of the College Board Online store at http://cbweb2.collegeboard.org/shopping/. Alternatively, call AP Order Services at (609) 771-7243. American Express, VISA, and MasterCard are accepted for payment.

If you are mailing your order, send it to the Advanced Placement Program, Dept. E-05, P.O. Box 6670, Princeton, NJ 08541-6670. Payment must accompany all orders not on an institutional purchase order or credit card, and checks should be made payable to the College Board.

The College Board pays fourth-class book rate postage (or its equivalent) on all prepaid orders; you should allow between four and six weeks for delivery. Postage will be charged on all orders requiring billing and/or requesting a faster method of shipment.

Publications may be returned within 30 days of receipt if postage is prepaid and publications are in resalable condition and still in print. Unless otherwise specified, orders will be filled with the currently available edition; prices are subject to change without notice.

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

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

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

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

The College Handbook with College Explorer® CD-ROM: $25.95 **SP, T, A, C**

Includes brief outlines of AP placement and credit policies at two- and four-year colleges across the country. Notes number of freshmen granted placement and/or credit for AP in the prior year.

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

Course Descriptions provide an outline of the AP course content, explain the kinds of skills students are expected to demonstrate in the corresponding introductory college-level course, and describe the AP Exam. They also provide sample multiple-choice questions with an answer key, as well as sample free-response questions. A set of Course Descriptions is available for $100. Not included in this set are Course Descriptions for Computer Science, Government and Politics, and Statistics, which are available for downloading from the AP section of the College Board website (free of charge).

Five-Year Set of Free-Response Questions: $5 **T**

This is our no-frills publication. Each booklet contains copies of all the free-response questions from the last five exams in its subject; nothing more, nothing less. Collectively, the questions represent a comprehensive sampling of the concepts assessed on the exam in recent years and will give teachers plenty of materials to use for essay-writing or problem-solving practice during the year. (If there have been any content changes to the exam in the past five years, it will be noted on the cover of the booklet.)

Grading, Interpreting, and Using Advanced Placement Examinations: Free A, C, T

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

Guide to the Advanced Placement Program: Free A

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

Released Exams: $20 T

About every four years, on a staggered schedule, the AP Program releases a complete copy (multiple-choice and free-response sections) of each exam, as in the case of the 1998 Physics B and Physics C Exams.

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

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

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

Teacher's Guides: $12 T

Whether you're about to teach an AP course for the first time, or you've done it for years but would like to get some fresh ideas for your classroom, the Teacher's Guide can be your adviser. It contains syllabi developed by high school teachers currently teaching the AP course and college faculty who teach the equivalent course at their institution. Along with detailed course outlines and innovative teaching tips, you'll also find extensive lists of recommended teaching resources.

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

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

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

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

What's in a Grade? (video): $15 T, C

AP Exams are composed of multiple-choice questions (scored by computer), and free-response questions that are scored by qualified professors and teachers. This video presents a behind-the-scenes look at the scoring process featuring footage shot on location at the 1992 AP Reading at Clemson University and other Reading sites. Using the AP European History Exam as a basis, the video documents the scoring process. It shows AP faculty consultants in action as they engage in scholarly debate to define precise scoring standards, then train others to recognize and apply those standards. Footage of other subjects, interviews with AP faculty consultants, and explanatory graphics round out the video.

AP PHYSICS

1997 – 98 DEVELOPMENT COMMITTEE

William Ingham, *Chair*
James Madison University
Harrisonburg, Virginia

Hirendra Chatterjee
Cherry Hill High School West
New Jersey

Hugh Henderson
Plano Senior High School
Texas

Ruth Howes
Ball State University
Muncie, Indiana

Gay Stewart
University of Arkansas
Fayetteville

Connie Wells
Pembroke Hill School
Kansas City, Missouri

Chief Faculty Consultant:
Michael Rulison
Oglethorpe University
Atlanta, GA

ETS Consultants:
G. Will Pfeiffenberger
Ann Marie Zolandz

IN. 255117

CollegeBoard AP