# AP® Physics C: Electricity and Magnetism Practice Exam

## From the 2013 Administration

## Contents



**Note: This publication shows the page numbers that appeared in the *2012–13 AP Exam Instructions* book and in the actual exam. This publication was not repaginated to begin with page 1.**

# Exam Instructions

The following contains instructions taken from the ***2012–13 AP Exam Instructions*** book.

# AP® Physics C: Electricity and Magnetism Exam

## Regularly Scheduled Exam Date: Monday afternoon, May 13, 2013

## Late-Testing Exam Date: Friday afternoon, May 24, 2013

### Section I: At a Glance

**Total Time:**
45 minutes
**Number of Questions:**
35
**Percent of Total Score:**
50%
**Writing Instrument:**
Pencil required
**Electronic Device:**
None allowed

### Section II: At a Glance

**Total Time:**
45 minutes
**Number of Questions:**
3
**Percent of Total Score:**
50%
**Writing Instrument:**
Either pencil or pen with black or dark blue ink
**Electronic Device:**
Calculator allowed
**Weight:**
The questions are weighted equally.

### Section I: Multiple Choice Booklet Instructions

Section I of this exam contains 35 multiple-choice questions. For these questions, fill in only the circles for numbers 1 through 35 on your answer sheet. A table of information that may be helpful is in the booklet. Rulers and straightedges may be used in this section.

Indicate all of your answers to the multiple-choice questions on the answer sheet. No credit will be given for anything written in this exam booklet, but you may use the booklet for notes or scratch work. After you have decided which of the suggested answers is best, completely fill in the corresponding circle 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.

Use your time effectively, working as quickly as you can without losing accuracy. Do not spend too much time on any one question. Go on to other questions and come back to the ones you have not answered if you have time. It is not expected that everyone will know the answers to all of the multiple-choice questions.

Your total score on the multiple-choice section is based only on the number of questions answered correctly. Points are not deducted for incorrect answers or unanswered questions.

### Section II: Free Response Booklet Instructions

The questions for Section II are printed in this booklet. You may use any blank space in the booklet for scratch work, but you must write your answers in the spaces provided for each answer. A table of information and lists of equations that may be helpful are in the booklet. Calculators, rulers, and straightedges may be used in this section.

All final numerical answers should include appropriate units. Credit for your work depends on 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 be awarded only for work that is clearly designated as the solution to a specific part of a question. Credit also depends on the quality of your solutions and explanations, so you should show your work.

Write clearly and legibly. Cross out any errors you make; erased or crossed-out work will not be scored. You may lose credit for incorrect work that is not crossed out.

Manage your time carefully. You may proceed freely from one question to the next. You may review your responses if you finish before the end of the exam is announced.

**What Proctors Need to Bring to This Exam**

- Exam packets
- Answer sheets
- AP Student Packs
- *2012-13 AP Coordinator's Manual*
- This book — *AP Exam Instructions*
- School Code and Home-School/Self-Study Codes
- Extra calculators
- Extra rulers or straightedges
- Pencil sharpener
- Extra No. 2 pencils with erasers
- Extra pens with black or dark blue ink
- Extra paper
- Stapler
- Watch
- Signs for the door to the testing room
  - "Exam in Progress"
  - "Cell phones are prohibited in the testing room"

Students are permitted to use four-function, scientific, or graphing calculators to answer the questions in Section II of the AP Physics C: Electricity and Magnetism Exam. Students are not allowed to use calculators in Section I. Before starting the exam administration, make sure each student has an appropriate calculator, and any student with a graphing calculator has a model from the approved list on page 42 of the *2012-13 AP Coordinator's Manual*. See pages 39–42 of the *2012-13 AP Coordinator's Manual* for more information. If a student does not have an appropriate calculator or has a graphing calculator not on the approved list, you may provide one from your supply. If the student does not want to use the calculator you provide or does not want to use a calculator at all, he or she must hand copy, date, and sign the release statement on page 40 of the *2012-13 AP Coordinator's Manual*.

During the administration of Section II, students may have no more than two calculators on their desks. Calculators may not be shared. Calculator memories do not need to be cleared before or after the exam. Students with Hewlett-Packard 48–50 Series and Casio FX-9860 graphing calculators may use cards designed for use with these calculators. Proctors should make sure infrared ports (Hewlett-Packard) are not facing each other. **Since graphing calculators can be used to store data, including text, proctors should monitor that students are using their calculators appropriately. Attempts by students to use the calculator to remove exam questions and/or answers from the room may result in the cancellation of AP Exam scores.**

Rulers and straightedges may be used for the entire exam.

Students may take both Physics C exams, Mechanics only, or Electricity and Magnetism only. The Mechanics exam is administered first, after which students taking both exams are given a break. Then the Electricity and Magnetism exam is administered. Prior to testing day, determine which students are taking only Electricity and Magnetism, and tell them to report to the testing room at approximately 2 p.m. (1 p.m. in Alaska). You should instruct them to wait quietly outside the room until told to come in, since students taking Mechanics may not have been dismissed yet. If all students are taking Electricity and Magnetism only, you must not begin the exam before 2 p.m.

## SECTION I: Multiple Choice

**! Do not begin the exam instructions below until you have completed the appropriate General Instructions for your group.**

This exam includes survey questions. The time allowed for the survey questions is in addition to the actual test-taking time.

Make sure that you begin the exam at the designated time.

*If you are giving the regularly scheduled exam, say:*

**It is Monday afternoon, May 13, and you will be taking the AP Physics C: Electricity and Magnetism Exam.**

*If you are giving the alternate exam for late testing, say:*

**It is Friday afternoon, May 24, and you will be taking the AP Physics C: Electricity and Magnetism Exam.**

**In a moment, you will open the packet that contains your exam materials. By opening this packet, you agree to all of the AP Program's policies and procedures outlined in the *2012-13 Bulletin for AP Students and Parents*. You may now remove the shrinkwrap from your exam packet and take out the Section I booklet, but do not open the booklet or the shrinkwrapped Section II materials. Put the white seals aside. . . .**

**Carefully remove the AP Exam label found near the top left of your exam booklet cover. Now place it on page 1 of your answer sheet on the dark blue box near the top right-hand corner that reads "AP Exam Label."**

If students accidentally place the exam label in the space for the number label or vice versa, advise them to leave the labels in place. They should not try to remove the label; their exam will be processed correctly.

**Read the statements on the front cover of Section I and look up when you have finished. . . .**

**Sign your name and write today's date. Look up when you have finished. . . .**

**Now print your full legal name where indicated. Are there any questions? . . .**

**Turn to the back cover and read it completely. Look up when you have finished. . . .**

**Are there any questions? . . .**

**Section I is the multiple-choice portion of the exam. You may never discuss these specific multiple-choice questions at any time in any form with anyone, including your teacher and other students. If you disclose these questions through any means, your AP Exam score will be canceled. Are there any questions? . . .**

**You must complete the answer sheet using a No. 2 pencil only. Mark all of your responses beginning on page 2 of your answer sheet, one response per question. Completely fill in the circles. If you need to erase, do so carefully and completely. No credit will be given for anything written in the exam booklet. Scratch paper is not allowed, but you may use the margins or any blank space in the exam booklet for scratch work. Rulers and straightedges may be used for the entire exam, but calculators are not allowed for Section I. Please put all of your calculators under your chair. Are there any questions? . . .**

**You have 45 minutes for this section. Open your Section I booklet and begin.**

Note Start Time here __________. Note Stop Time here __________. Check that students are marking their answers in pencil on their answer sheets, and that they are not looking at their shrinkwrapped Section II booklets. After 45 minutes, say:

**Stop working and turn to the last page of your booklet. . . .**

**You have 2 minutes to answer Questions 101–106. These are survey questions and will not affect your score. You may not go back to work on any of the exam questions. You may now begin.**

To help you and your proctors make sure students are not working on the exam questions, the two pages with the survey questions are identified with a large S on the upper corner of each page. Give students 2 minutes to answer the survey questions. Then say:

**Close your booklet and put your answer sheet on your desk, face up. Make sure you have your AP number label and an AP Exam label on page 1 of your answer sheet. I will now collect your answer sheet.**

Collect an answer sheet from each student. Check that each answer sheet has an AP number label and an AP Exam label. Then say:

**Now you must seal your exam booklet. Remove the white seals from the backing and press one on each area of your exam booklet cover marked "PLACE SEAL HERE." Fold each seal over the back cover. When you have finished, place the booklet on your desk, face up. I will now collect your Section I booklet. . . .**

## SECTION II: Free Response

Check that each student has signed the front cover of the sealed Section I booklet. When all Section I materials have been collected and accounted for, say:

**May I have everyone's attention? Place your Student Pack on your desk. . . .**

**You may now remove the shrinkwrap from the Section II packet, but do not open the exam booklet until you are told to do so. . . .**

**Read the bulleted statements on the front cover of the exam booklet. Look up when you have finished. . . .**

**Now place an AP number label on the shaded box. If you don't have any AP number labels, write your AP number in the box. Look up when you have finished. . . .**

**Read the last statement. . . .**

**Using your pen, print the first, middle and last initials of your legal name in the boxes and print today's date where indicated. This constitutes your signature and your agreement to the statements on the front cover. . . .**

**Turn to the back cover and complete Item 1 under "Important Identification Information." Print the first two letters of your last name and the first letter of your first name in the boxes. Look up when you have finished. . . .**

**In Item 2, print your date of birth in the boxes. . . .**

**In Item 3, write the school code you printed on the front of your Student Pack in the boxes. . . .**

**Read Item 4. . . .**

**Are there any questions? . . .**

**I need to collect the Student Pack from anyone who will be taking another AP Exam. You may keep it only if you are not taking any other AP Exams this year. If you have no other AP Exams to take, place your Student Pack under your chair now. . . .**

**While Student Packs are being collected, read the information on the back cover of the exam booklet. Do not open the booklet until you are told to do so. Look up when you have finished. . . .**

Collect the Student Packs. Then say:

**Are there any questions? . . .**

**Calculators may be used for Section II. You may get your calculators from under your chair and place them on your desk. . . .**

**You have 45 minutes to complete Section II. You are responsible for pacing yourself, and may proceed freely from one question to the next. You must write your answers in the exam booklet using a pen or a No. 2 pencil. If you use a pencil, be sure that your writing is dark enough to be easily read. If you need more paper during the exam, raise your hand. At the top of each extra piece of paper you use be sure to write only your AP number and the number of the question you are working on. Do not write your name. Are there any questions? . . .**

**You may begin.**

Note Start Time here __________. Note Stop Time here __________. Check that students are writing their answers in the exam booklet. You should also make sure that Hewlett-Packard calculators' infrared ports are not facing each other and that students are not sharing calculators. After 35 minutes, say:

**There are 10 minutes remaining.**

After 10 minutes, say:

**Stop working and close your exam booklet. Place it on your desk, face up. . . .**

If any students used extra paper for the free-response section, have those students staple the extra sheet/s to the first page corresponding to that question in their exam booklets. Then say:

> **Remain in your seat, without talking, while the exam materials are collected. . . .**

Collect a Section II booklet from each student. Check for the following:

- Exam booklet front cover: The student placed an AP number label on the shaded box, and printed his or her initials and today's date.
- Exam booklet back cover: The student completed the "Important Identification Information" area.

When all exam materials have been collected and accounted for, return to students any electronic devices you may have collected before the start of the exam.

*If you are giving the regularly scheduled exam, say:*

> **You may not discuss these specific free-response questions with anyone unless they are released on the College Board website in about two days. Your AP score results will be delivered online in July.**

*If you are giving the alternate exam for late testing, say:*

> **None of the questions in this exam may ever be discussed or shared in any way at any time. Your AP score results will be delivered online in July.**

If any students completed the AP number card at the beginning of this exam, say:

> **Please remember to take your AP number card with you. You will need the information on this card to view your scores and order AP score reporting services online.**

Then say:

> **You are now dismissed.**

All exam materials should be put in secure storage until they are returned to the AP Program after your school's last administration. Before storing materials, check the "School Use Only" section on page 1 of the answer sheet and:

- Fill in the appropriate section number circle in order to access a separate AP Instructional Planning Report (for regularly scheduled exams only) or subject score roster at the class section or teacher level. See "Post-Exam Activities" in the *2012-13 AP Coordinator's Manual*.
- Check your list of students who are eligible for fee reductions and fill in the appropriate circle on their registration answer sheets.

# Student Answer Sheet for the Multiple-Choice Section

Use this section to capture student responses. (Note that the following answer sheet is a sample, and may differ from one used in an actual exam.)

AP® Answer Sheet 2013

**AP Number Label** (from Student Pack)

B123456789T

**AP Exam Label** (from Section I Booklet)



CollegeBoard

## COMPLETE THIS AREA AT EVERY EXAM. USE NO. 2 PENCIL ONLY

To maintain the security of the exam and the validity of my AP score, I will allow no one else to see the multiple-choice questions. I will seal the multiple-choice booklet when asked to do so, and I will not discuss these questions with anyone at any time after completing the section. I am aware of and agree to the AP Program's policies and procedures as outlined in the *2012-13 Bulletin for AP Students and Parents*, including using testing accommodations (e.g., extended time, computer, etc.) only if I have been preapproved by College Board Services for Students with Disabilities.

**A. SIGNATURE** — Sign your legal name as it will appear on your college applications. — Date

**B. LEGAL NAME** — Omit apostrophes, Jr., II.

Legal Last Name — First 15 Letters | Legal 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 –

**C. YOUR AP NUMBER**

0 1 2 3 4 5 6 7 8 9

**D. EXAM DATE**

Month: 0 1 | 0 1 2 3 4 5 6 7 8 9

Day: 0 1 2 3 | 0 1 2 3 4 5 6 7 8 9

**E. EXAM START TIME**

AM: 6 7 8 9 10 11

PM: 12 1 2 3 4 5

**F. MULTIPLE-CHOICE BOOKLET SERIAL NUMBER**

S

0 1 2 3 4 5 6 7 8 9

**G. ONLINE PROVIDER CODE**

0 1 2 3 4 5 6 7 8 9

**H. AP EXAM I AM TAKING USING THIS ANSWER SHEET**

Exam Name: | Form: | Form Code:

768252

**SCHOOL USE ONLY**

Section Number: 1 2 3 4 5 6 7 8 9

Fee Reduction Granted: 1 Option 1 2 Option 2

## COMPLETE THIS AREA ONLY ONCE.

**I. AREA CODE AND PHONE NUMBER**

0 1 2 3 4 5 6 7 8 9

INTERNATIONAL PHONE

**J. SCHOOL YOU ATTEND**

SCHOOL CODE

0 1 2 3 4 5 6 7 8 9

School Name

City

State

Country

**K. DATE OF BIRTH**

Month: Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

Day: 0 1 2 3 | 0 1 2 3 4 5 6 7 8 9

Year: 0 1 2 3 4 5 6 7 8 9

**L. SOCIAL SECURITY NUMBER (Optional)**

0 1 2 3 4 5 6 7 8 9

**M. COLLEGE TO RECEIVE YOUR AP SCORE REPORT**

COLLEGE CODE

0 1 2 3 4 5 6 7 8 9

Using the college code listed in the AP Student Pack, indicate the **ONE** college that you want to receive your AP score report.

College Name

City

State

Country

**N. CURRENT GRADE LEVEL**

Not yet in 9th grade

9th

10th

11th

12th

No longer in high school

**O. STUDENT SEARCH SERVICE®**

Yes No

## COMPLETE THIS AREA AT EACH EXAM (IF APPLICABLE)

### P. SURVEY QUESTIONS — Answer the survey questions in the AP Student Pack. Do not put responses to exam questions in this section.

| | | | | | |
|---|---|---|---|---|---|
| 1 | A B C D E F G H I | 4 | A B C D E F G H I | 7 | A B C D E F G H I |
| 2 | A B C D E F G H I | 5 | A B C D E F G H I | 8 | A B C D E F G H I |
| 3 | A B C D E F G H I | 6 | A B C D E F G H I | 9 | A B C D E F G H I |

### Q. LANGUAGE — Do not complete this section unless instructed to do so.

**If this answer sheet is for the French Language and Culture, German Language and Culture, Italian Language and Culture, Spanish Language, or Spanish Literature and Culture Exam, please answer the following questions. Your responses will not affect your score.**

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

## QUESTIONS 1–75

**Indicate your answers to the exam questions in this section (pages 2 and 3). Use a No. 2 pencil only. Mark only one response per question. If a question has only four answer options, do not mark option E. Answers written in the multiple-choice booklet will not be scored.**

**Your answer sheet will be scored by machine. Any improper gridding may affect your score.**

- **Completely fill in the circle for your response next to the number of the question you are answering.**
- **Erase carefully and completely. Stray marks and smudges could be read as answers.**

| | | | | | |
|---|---|---|---|---|---|
| 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 |

DO NOT WRITE IN THIS AREA

QUESTIONS 76–120

Be sure each mark is dark and completely fills the circle. If a question has only four answer options, do not mark option E.

| | | | | | |
|---|---|---|---|---|---|
| 76 | A B C D E | 91 | A B C D E | 106 | A B C D E |
| 77 | A B C D E | 92 | A B C D E | 107 | A B C D E |
| 78 | A B C D E | 93 | A B C D E | 108 | A B C D E |
| 79 | A B C D E | 94 | A B C D E | 109 | A B C D E |
| 80 | A B C D E | 95 | A B C D E | 110 | A B C D E |
| 81 | A B C D E | 96 | A B C D E | 111 | A B C D E |
| 82 | A B C D E | 97 | A B C D E | 112 | A B C D E |
| 83 | A B C D E | 98 | A B C D E | 113 | A B C D E |
| 84 | A B C D E | 99 | A B C D E | 114 | A B C D E |
| 85 | A B C D E | 100 | A B C D E | 115 | A B C D E |
| 86 | A B C D E | 101 | A B C D E | 116 | A B C D E |
| 87 | A B C D E | 102 | A B C D E | 117 | A B C D E |
| 88 | A B C D E | 103 | A B C D E | 118 | A B C D E |
| 89 | A B C D E | 104 | A B C D E | 119 | A B C D E |
| 90 | A B C D E | 105 | A B C D E | 120 | A B C D E |

For Students Taking AP Biology

Write your answer in the boxes at the top of the griddable area and fill in the corresponding circles.
Mark only one circle in any column. You will receive credit only if the circles are filled in correctly.

121 122 123 124 125 126

| | | | | | |
|---|---|---|---|---|---|
| | | / | / | / | |
| – | . | . | . | . | . |
| | | 0 | 0 | 0 | 0 |
| | 1 | 1 | 1 | 1 | 1 |
| | 2 | 2 | 2 | 2 | 2 |
| | 3 | 3 | 3 | 3 | 3 |
| | 4 | 4 | 4 | 4 | 4 |
| | 5 | 5 | 5 | 5 | 5 |
| | 6 | 6 | 6 | 6 | 6 |
| | 7 | 7 | 7 | 7 | 7 |
| | 8 | 8 | 8 | 8 | 8 |
| | 9 | 9 | 9 | 9 | 9 |

ETS USE ONLY

| SELECTED MEDIA EXAMS | R | W | O | OTHER EXAMS | R | W | O |
|---|---|---|---|---|---|---|---|
| PT02 | | | | TOTAL | | | |
| PT03 | | | | Subscore (if applicable) | | | |
| PT04 | | | | Subscore (if applicable) | | | |

| | | |
|---|---|---|
| Exam | | 0 1 2 3 4 5 6 7 8 9 |
| | | 0 1 2 3 4 5 6 7 8 9 |
| Exam | | 0 1 2 3 4 5 6 7 8 9 |
| | | 0 1 2 3 4 5 6 7 8 9 |



DO NOT WRITE IN THIS AREA

## COMPLETE THIS AREA ONLY ONCE.

### R. YOUR MAILING ADDRESS

Use the address abbreviations from your AP Student Pack. Fill in only one circle per column. Indicate a space in your address by leaving a blank box; do not grid that column.

**STREET ADDRESS** (include street number, street name, apartment number, etc.)

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 0 1 2 3 4 5 6 7 8 9 /

**CITY**

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

**STATE**

AK AL AR AZ CA CO CT DC DE FL GA HI IA ID IL IN KS KY LA MA MD ME MI MN MO MS MT NC ND NE NH NJ NM NV NY OH OK OR PA RI SC SD TN TX UT VA VT WA WI WV WY Puerto Rico AA AE AP Other

**ZIP OR POSTAL CODE**

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 0 1 2 3 4 5 6 7 8 9 /

**COUNTRY CODE**

0 1 2 3 4 5 6 7 8 9

### V. SEX

- Female
- Male

### W. WHICH LANGUAGE DO YOU KNOW BEST?

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

### X. ETHNICITY/RACE

- American Indian or Alaska Native
- Asian, Asian American or Pacific Islander
- Black or African American
- Mexican or Mexican American
- Puerto Rican
- Other Hispanic, Latino or Latin American
- White
- Other

### Y. PARENTAL EDUCATION LEVEL

| Father/ Male Guardian | Mother/ Female Guardian | |
|---|---|---|
| ◯ | ◯ | Grade school |
| ◯ | ◯ | Some high school |
| ◯ | ◯ | High school diploma or equivalent |
| ◯ | ◯ | Business or trade school |
| ◯ | ◯ | Some college |
| ◯ | ◯ | Associate or two-year degree |
| ◯ | ◯ | Bachelor's or four-year degree |
| ◯ | ◯ | Some graduate or professional school |
| ◯ | ◯ | Graduate or professional degree |

### S. FOR STUDENTS OUTSIDE THE UNITED STATES ONLY

If your address does not fit in the spaces provided in Item R, fill in as many circles as you can, then fill in the circle in Item S and print the remainder of your address in the spaces provided.

| Address | City | State or Province | Country | ZIP or Postal Code |
|---|---|---|---|---|
| | | | | |

### T. STUDENT IDENTIFIER (Student ID Number)

### U. EMAIL ADDRESS

By providing your email address, you are granting the College Board permission to use your email in accordance with the policies in the *2012-13 Bulletin for AP Students and Parents.*

# Section I: Multiple-Choice Questions

This is the multiple-choice section of the 2013 AP exam. It includes cover material and other administrative instructions to help familiarize students with the mechanics of the exam. (Note that future exams may differ in look from the following content.)

PLACE SEAL HERE

# AP® Physics C: Electricity and Magnetism Exam

## SECTION I: Multiple Choice

2013

**DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.**

### At a Glance

**Total Time**
45 minutes
**Number of Questions**
35
**Percent of Total Score**
50%
**Writing Instrument**
Pencil required
**Electronic Device**
None allowed

### Instructions

Section I of this exam contains 35 multiple-choice questions. For these questions, fill in only the circles for numbers 1 through 35 on your answer sheet. A table of information that may be helpful is in the booklet. Rulers and straightedges may be used in this section.

Indicate all of your answers to the multiple-choice questions on the answer sheet. No credit will be given for anything written in this exam booklet, but you may use the booklet for notes or scratch work. After you have decided which of the suggested answers is best, completely fill in the corresponding circle 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. Here is a sample question and answer.

| Sample Question | Sample Answer |
|---|---|
| Chicago is a<br>(A) state<br>(B) city<br>(C) country<br>(D) continent<br>(E) village | Ⓐ ● Ⓒ Ⓓ Ⓔ |

Use your time effectively, working as quickly as you can without losing accuracy. Do not spend too much time on any one question. Go on to other questions and come back to the ones you have not answered if you have time. It is not expected that everyone will know the answers to all of the multiple-choice questions.

Your total score on the multiple-choice section is based only on the number of questions answered correctly. Points are not deducted for incorrect answers or unanswered questions.

PLACE SEAL HERE

Form I
Form Code 4JBP4-S
82

PLACE SEAL HERE
DO NOT seal answer sheet inside

## TABLE OF INFORMATION DEVELOPED FOR 2012

### CONSTANTS AND CONVERSION FACTORS

| | |
|---|---|
| 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 |
| Avogadro's number, | $N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$ |
| Universal gas constant, | $R = 8.31\ \text{J/(mol}\cdot\text{K)}$ |
| Boltzmann's constant, | $k_B = 1.38 \times 10^{-23}$ J/K |
| Electron charge magnitude, | $e = 1.60 \times 10^{-19}$ C |
| 1 electron volt, | $1\ \text{eV} = 1.60 \times 10^{-19}$ J |
| Speed of light, | $c = 3.00 \times 10^{8}$ m/s |
| Universal gravitational constant, | $G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg}\cdot\text{s}^2$ |
| Acceleration due to gravity at Earth's surface, | $g = 9.8\ \text{m/s}^2$ |
| 1 unified atomic mass unit, | $1\ \text{u} = 1.66 \times 10^{-27}\ \text{kg} = 931\ \text{MeV}/c^2$ |
| 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, | $\mu_0 = 4\pi \times 10^{-7}\ \text{(T}\cdot\text{m)/A}$ |
| Magnetic constant, | $k' = \mu_0/4\pi = 1 \times 10^{-7}\ \text{(T}\cdot\text{m)/A}$ |
| 1 atmosphere pressure, | $1\ \text{atm} = 1.0 \times 10^{5}\ \text{N/m}^2 = 1.0 \times 10^{5}$ Pa |

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

**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**

| $\theta$ | $0^\circ$ | $30^\circ$ | $37^\circ$ | $45^\circ$ | $53^\circ$ | $60^\circ$ | $90^\circ$ |
|---|---|---|---|---|---|---|---|
| $\sin\theta$ | 0 | $1/2$ | $3/5$ | $\sqrt{2}/2$ | $4/5$ | $\sqrt{3}/2$ | 1 |
| $\cos\theta$ | 1 | $\sqrt{3}/2$ | $4/5$ | $\sqrt{2}/2$ | $3/5$ | $1/2$ | 0 |
| $\tan\theta$ | 0 | $\sqrt{3}/3$ | $3/4$ | 1 | $4/3$ | $\sqrt{3}$ | $\infty$ |

The following conventions are used in this exam.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.

II. The direction of any electric current is the direction of flow of positive charge (conventional current).

III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

## PHYSICS C: ELECTRICITY AND MAGNETISM

## SECTION I

**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 circle on the answer sheet.

1. A circuit contains a length of tungsten wire with resistance $R$. An increase in the resistance would result if which of the following could be decreased?

   (A) The resistivity of the tungsten
   (B) The cross-sectional area of the wire
   (C) The length of the wire
   (D) The temperature of the wire
   (E) The current in the wire

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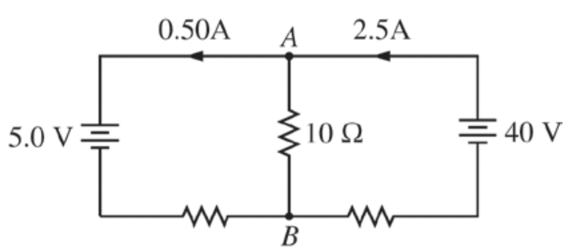
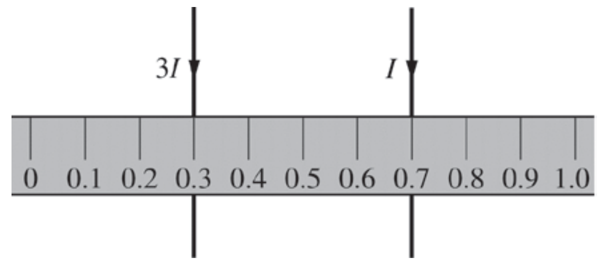



2. In the circuit shown above, a student has measured the currents that are given in the diagram, but does not know all the resistance values. The magnitude of the potential difference between points $A$ and $B$ is

   (A) 10 V
   (B) 20 V
   (C) 30 V
   (D) 35 V
   (E) 40 V

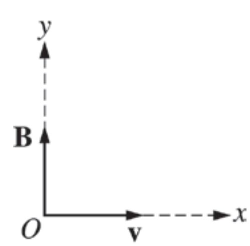
3. A 0.20 μF capacitor and a 0.10 μF capacitor are connected in parallel to a 6.0 V battery. The potential difference across the 0.20 μF capacitor is most nearly

   (A) 1.3 V
   (B) 2.0 V
   (C) 3.0 V
   (D) 4.0 V
   (E) 6.0 V




4. Two parallel, straight conductors carry currents $3I$ and $I$ in the same direction, as shown in the figure above. A plastic meterstick is held against the wires so that they are positioned at the 0.3 m and 0.7 m mark, respectively. At what position on the meterstick is the magnetic field zero?

   (A) Nowhere on the meterstick
   (B) At the 0.1 m mark
   (C) At the 0.4 m mark
   (D) At the 0.6 m mark
   (E) At the 0.9 m mark




5. A positively charged particle moves with velocity **v** in the positive $x$-direction in a uniform magnetic field **B** directed in the positive $y$-direction, as shown above. The particle experiences a force in what direction?

   (A) Perpendicularly out of the plane of the page
   (B) Perpendicularly into the plane of the page
   (C) Positive $x$-direction
   (D) Negative $x$-direction
   (E) Positive $y$-direction



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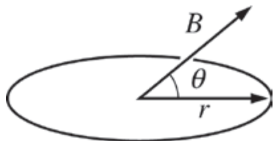



6. A circular loop of radius $r$ is located in a uniform magnetic field of magnitude $B$ directed at an angle $\theta$ to the plane of the loop, as shown above. What is the magnetic flux through the loop?

   (A) $\pi r^2 B \sin\theta$

   (B) $\pi r^2 B \cos\theta$

   (C) $\pi r^2 B$

   (D) $2\pi r B \cos\theta$

   (E) $2\pi r B$

7. A circular loop of wire of radius $R$ is perpendicular to a magnetic field whose magnitude as a function of time $t$ is given by the equation $B = bt^2 + ct$, where $b$ and $c$ are positive, nonzero constants. What is the magnitude of the emf induced in the loop as a function of time $t$?

   (A) $2\pi R\left(bt^2 + ct\right)$

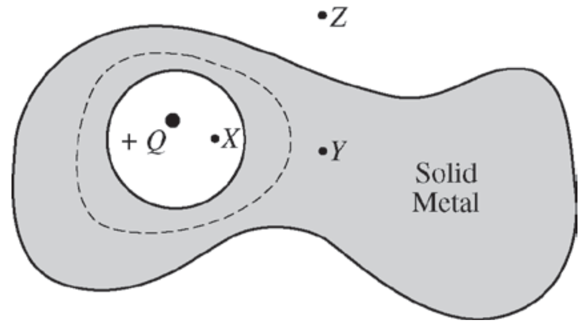
   (B) $2\pi R(2bt + c)$

   (C) $\pi R^2\left(bt^2 + ct\right)$

   (D) $\pi R^2(bt + c)$

   (E) $\pi R^2(2bt + c)$

**Questions 8-10**




A charge $+Q$ is inside a hollow region in an electrically neutral piece of solid metal, as shown above. The dashed line represents a Gaussian surface within the metal that completely encloses the hollow region.

8. At which of the three labeled points is the electric field equal to zero?

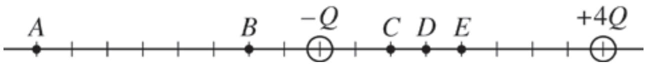
   (A) $X$ only
   (B) $Y$ only
   (C) $X$ and $Z$ only
   (D) $Y$ and $Z$ only
   (E) $X$, $Y$, and $Z$

9. What is the net electric flux through the Gaussian surface?

   (A) $-Q/\epsilon_0$
   (B) Zero
   (C) $+Q/\epsilon_0$
   (D) $+2Q/\epsilon_0$
   (E) It cannot be determined without knowing the exact shape of the Gaussian surface.

10. Which of the following correctly relates the electric potentials $V$ at points $X$, $Y$, and $Z$?

   (A) $V_X < V_Y < V_Z$
   (B) $V_Y < V_X < V_Z$
   (C) $V_Y < V_Z < V_X$
   (D) $V_Z < V_X < V_Y$
   (E) $V_Z < V_Y < V_X$




11. Two small spheres having charges $-Q$ and $+4Q$ are situated as shown above. The electric force on a small test charge will be zero if it is placed at point

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

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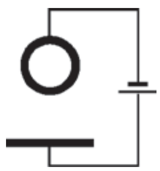


12. A conducting plate and a conducting cylinder are connected to a battery, as shown above. Which of the following best represents the electric field between the two objects?

(A) 

(B) 

(C) 

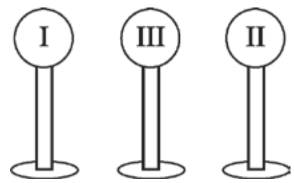
(D) 

(E) 

13. A uniform electric field exists in which of the following regions?

I. Around an infinite line of uniform linear charge density
II. On either side of an infinite thin sheet of uniform charge density
III. Between the spherical shells of a charged spherical capacitor

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




14. Three identical conducting spheres are mounted on insulating handles, as shown above. Spheres I and II have equal charges of $+Q$ and are separated by a fixed distance. They repel each other with an electrostatic force of magnitude $F$. Sphere III, initially uncharged, is first touched to sphere I, then to sphere II, and then removed. If the charge distribution on each sphere is assumed to always be spherical, the new magnitude of the electrostatic force between spheres I and II is

(A) zero
(B) $\frac{F}{16}$
(C) $\frac{F}{4}$
(D) $\frac{F}{2}$
(E) $\frac{3F}{8}$

15. Which of the following describes the electric field and electric potential inside a charged solid spherical conductor that is in electrostatic equilibrium?

| | Field | Potential |
|---|---|---|
| (A) | Zero | Zero |
| (B) | Nonzero and uniform | Zero |
| (C) | Nonzero and uniform | Nonzero and uniform |
| (D) | Zero | Nonzero and uniform |
| (E) | Zero | Nonzero and nonuniform |

16. A parallel-plate capacitor is connected to a battery until fully charged. If the battery remains connected while the separation between the plates is increased, which of the following remains constant?

(A) Potential difference between the plates
(B) Capacitance
(C) Magnitude of the charge on each plate
(D) Stored electrostatic energy
(E) Electric field intensity in the region between the plates


17. Two long, straight wires are fixed parallel to one another a distance $d_0$ apart. The wires carry equal constant currents $I_0$ in the same direction. The attractive magnetic force per unit length between them is $f = F/L$. What is the force per unit length between the wires if their separation is $2d_0$ and each carries current $2I_0$ ?

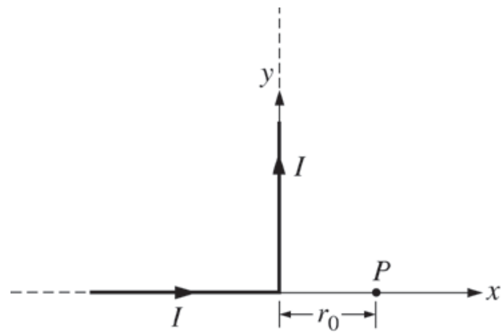
(A) $f/4$

(B) $f/2$

(C) $f$

(D) $3f/2$

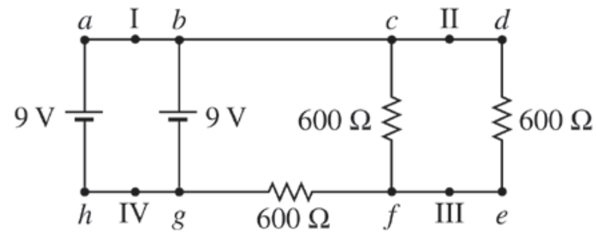
(E) $2f$




18. Suppose that the magnetic field due to a very long straight wire carrying current $I$ has magnitude $B_0$ at a distance $r_0$ from the wire. If the wire is bent into a right angle and placed on the $xy$-axes as shown above, the magnitude of the magnetic field at point $P$ on the $x$-axis at a distance of $r_0$ from the bend is most nearly

    (A) zero
    (B) $B_0/4$
    (C) $B_0/2$
    (D) $B_0$
    (E) $2B_0$

**Questions 19-21**




Two 9 V batteries and three identical 600 Ω resistors are connected in a circuit, as shown above. Neglect internal resistance in the batteries and consider all meters to be ideal.

19. A voltmeter would read 6 V if connected correctly between which two points in the circuit?

    (A) $a$ and $b$
    (B) $a$ and $f$
    (C) $b$ and $f$
    (D) $c$ and $d$
    (E) $f$ and $g$

20. Ammeters are inserted at points I, II, III, and IV. At which of the other points would the ammeter register the same current as the ammeter at point IV ?

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

21. What is the total power dissipated in the three resistors?

    (A) 0.023 W
    (B) 0.045 W
    (C) 0.090 W
    (D) 0.36 W
    (E) 9.0 W



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22. A charge $+q$ is placed at the center of a cube. What is the flux of the electric field through one face of the cube?

(A) 0

(B) $\dfrac{q}{\epsilon_0}$

(C) $\dfrac{q}{6\epsilon_0}$

(D) $6\epsilon_0 q$

(E) The flux through one face cannot be determined from the information given.

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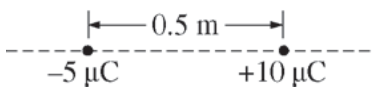
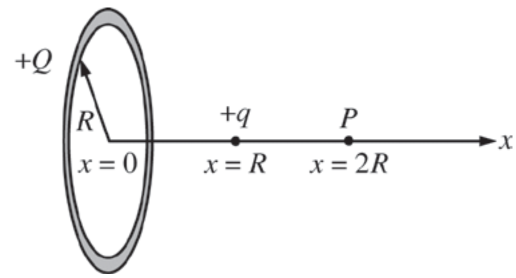



23. A negative 5 μC charge is located 0.5 m from a positive 10 μC charge as shown above. At how many positions (excluding infinity) on a line passing through both charges is the electric potential equal to zero?

(A) 0
(B) 1
(C) 2
(D) 3
(E) 4




24. A thin ring of radius $R$ has charge $+Q$ distributed uniformly around the ring. The center of the ring is at the origin of an $x$-axis perpendicular to the plane of the ring, as shown in the figure above. A point charge $+q$ on the $x$-axis at position $x = R$ is released from rest. What is its kinetic energy when it reaches position $P$ at $x = 2R$ on the $x$-axis?

(A) $\dfrac{3}{10}\dfrac{kQq}{R}$

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

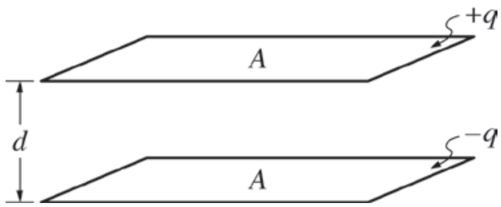
(C) $\dfrac{1}{\sqrt{3}}\dfrac{kQq}{R}$

(D) $\dfrac{kQq}{R}$

(E) $\dfrac{kQq}{R}\left(\dfrac{1}{\sqrt{2}} - \dfrac{1}{\sqrt{5}}\right)$

25. A parallel-plate capacitor is charged and the battery is removed. If a dielectric with dielectric constant $k > 1$ is then inserted in the capacitor, which of the following will decrease?

(A) The voltage across the capacitor
(B) The charge on one of the capacitor plates
(C) The distance between the capacitor plates
(D) The capacitance of the capacitor
(E) The resistance of the capacitor




26. A parallel-plate capacitor of capacitance $C$ consists of two plates of area $A$ separated by distance $d$ as shown above. The upper and lower plates are given a net charge of $+q$ and $-q$, respectively. What is the electric field between the plates?

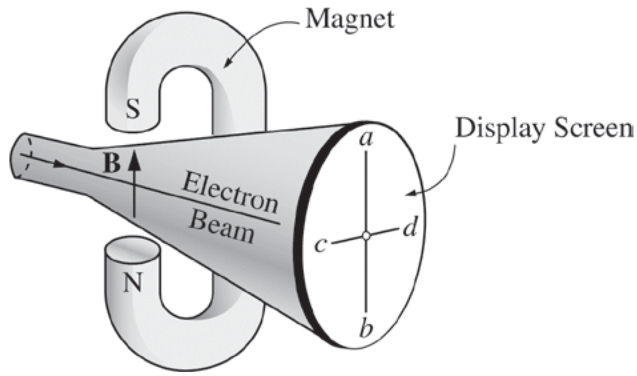
 (A) Zero
 (B) $\dfrac{C}{2qd}$
 (C) $\dfrac{C}{qd}$
 (D) $\dfrac{2q}{Cd}$
 (E) $\dfrac{q}{Cd}$

27. Five air-filled parallel-plate capacitors have the plate areas and plate separations listed below, where $A$ and $d$ are constants. The capacitors are each connected to the same potential difference. Which capacitor stores the greatest amount of energy?

| | Area | Separation |
|---|---|---|
| (A) | $2A$ | $d/2$ |
| (B) | $2A$ | $2d$ |
| (C) | $A$ | $d$ |
| (D) | $A/2$ | $d/2$ |
| (E) | $A/2$ | $2d$ |

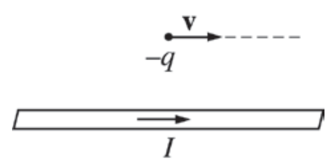
28. A compass needle is in a uniform magnetic field **B** with its north-seeking pole pointing in the direction of the field. The net magnetic force on the compass needle is

 (A) in the direction of **B**
 (B) in the direction of $-\mathbf{B}$
 (C) perpendicular to the plane determined by **B** and the needle
 (D) in the same plane as **B** and the needle, but perpendicular to the needle
 (E) zero




29. A horizontal electron beam in an oscilloscope is aimed at the center of the display screen, as shown in the diagram above. A C-shaped magnet is placed around the oscilloscope, producing a vertical magnetic field **B**, which is perpendicular to the beam. Which way, if any, will the beam be deflected by the magnetic field?

 (A) Toward point $a$
 (B) Toward point $b$
 (C) Toward point $c$
 (D) Toward point $d$
 (E) The beam will not be deflected.




30. A negative charge $-q$ is moving with a velocity **v** to the right, parallel to a wire that is carrying a current $I$ to the right, as shown above. The direction of the force on the charge due to the magnetic field produced by the wire is

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



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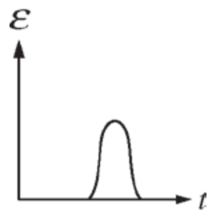
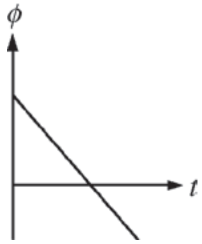


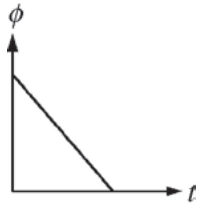

31. The graph above shows an emf $\mathcal{E}$ induced in a loop of wire as a function of time $t$. Which of the following graphs best corresponds to the magnetic flux passing through the loop of wire as a function of time $t$ ?

(A) $\phi$

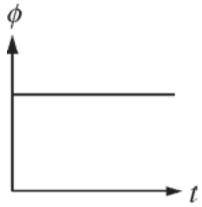
(B) $\phi$



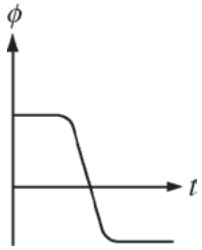
(C) $\phi$

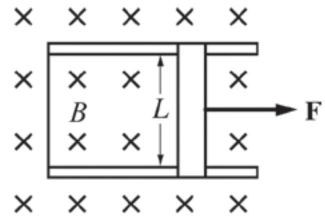


(D) $\phi$



(E) $\phi$






Top View

32. A metal rod of length $L$ that can slide on horizontal frictionless metal rails is moved through a uniform magnetic field of magnitude $B$ that is perpendicular to the rails, as shown in the figure above. The other ends of the rails are connected by a wire to form a circuit of resistance $R$. An external force of magnitude $F$ is applied to the rod so that the rod maintains a constant speed $\upsilon$. What is the power supplied by the force?

(A) $\dfrac{B^2L^2\upsilon}{R}$

(B) $\dfrac{B^2L^2\upsilon}{R^2}$

(C) $\dfrac{B^2L\upsilon^2}{R}$

(D) $\dfrac{B^2L^2\upsilon^2}{R}$

(E) $\dfrac{B^2L\upsilon^3}{R}$



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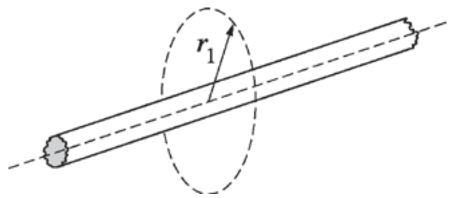



33. An electric field is produced by the very long, uniformly charged rod shown above. If the strength of the electric field is $E_1$ at a distance $r_1$ from the axis of the rod, at what distance from the axis is the field strength $\frac{E_1}{10}$?

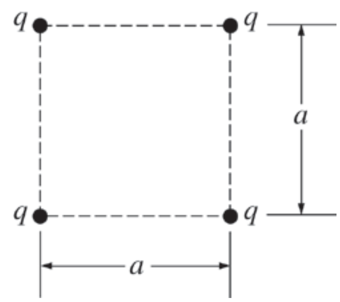
(A) $\frac{r_1}{100}$

(B) $\frac{r_1}{10}$

(C) $\sqrt{10}\, r_1$

(D) $10\, r_1$

(E) $100\, r_1$




34. Four identical point charges $q$ are fixed at the corners of a square with sides of length $a$, as shown above. The potential at the center of the square due to these charges is

(A) zero

(B) $\frac{1}{4\pi\epsilon_0}\frac{q}{\sqrt{2}a}$

(C) $\frac{1}{4\pi\epsilon_0}\frac{q}{a}$

(D) $\frac{1}{4\pi\epsilon_0}\frac{4q}{a}$

(E) $\frac{1}{4\pi\epsilon_0}\frac{4\sqrt{2}q}{a}$

35. A total charge $Q$ is uniformly distributed throughout a spherical volume of radius $a$. Which of the following is a dimensionally correct expression for the potential difference between the center of the sphere and its surface?

(A) $\left(\frac{1}{8\pi\epsilon_0}\right)Q$

(B) $\left(\frac{1}{8\pi\epsilon_0}\right)Qa^2$

(C) $\left(\frac{1}{8\pi\epsilon_0}\right)Qa$

(D) $\left(\frac{1}{8\pi\epsilon_0}\right)\frac{Q}{a}$

(E) $\left(\frac{1}{8\pi\epsilon_0}\right)\frac{Q}{a^2}$



GO ON TO THE NEXT PAGE.

# S T O P

**END OF ELECTRICITY AND MAGNETISM SECTION I**

**IF YOU FINISH BEFORE TIME IS CALLED,**
**YOU MAY CHECK YOUR WORK ON ELECTRICITY AND MAGNETISM SECTION I ONLY.**

**DO NOT TURN TO ANY OTHER TEST MATERIALS.**

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**MAKE SURE YOU HAVE DONE THE FOLLOWING.**

- **PLACED YOUR AP NUMBER LABEL ON YOUR ANSWER SHEET**
- **WRITTEN AND GRIDDED YOUR AP NUMBER CORRECTLY ON YOUR ANSWER SHEET**
- **TAKEN THE AP EXAM LABEL FROM THE FRONT OF THIS BOOKLET AND PLACED IT ON YOUR ANSWER SHEET**

## Section II: Free-Response Questions

This is the free-response section of the 2013 AP exam. It includes cover material and other administrative instructions to help familiarize students with the mechanics of the exam. (Note that future exams may differ in look from the following content.)

# AP® Physics C: Electricity and Magnetism Exam

## SECTION II: Free Response

2013

**DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.**

### At a Glance

**Total Time**
45 minutes
**Number of Questions**
3
**Percent of Total Score**
50%
**Writing Instrument**
Either pencil or pen with black or dark blue ink
**Electronic Devices**
Calculator allowed
**Weight**
The questions are weighted equally.

### IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name

   First letter of your first name

2. Date of birth

   Month Day Year

3. Six-digit school code

4. Unless I check the box below, I grant the College Board the unlimited right to use, reproduce, and publish my free-response materials, both written and oral, for educational research and instructional purposes. My name and the name of my school will not be used in any way in connection with my free-response materials. I understand that I am free to mark "No" with no effect on my score or its reporting.

   No, I do not grant the College Board these rights.

### Instructions

The questions for Section II are printed in this booklet. You may use any blank space in the booklet for scratch work, but you must write your answers in the spaces provided for each answer. A table of information and lists of equations that may be helpful are in the booklet. Calculators, rulers, and straightedges may be used in this section.

All final numerical answers should include appropriate units. Credit for your work depends on 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 be awarded only for work that is clearly designated as the solution to a specific part of a question. Credit also depends on the quality of your solutions and explanations, so you should show your work.

Write clearly and legibly. Cross out any errors you make; erased or crossed-out work will not be scored. You may lose credit for incorrect work that is not crossed out.

Manage your time carefully. You may proceed freely from one question to the next. You may review your responses if you finish before the end of the exam is announced.

**Form I**
**Form Code 4BBP2-S3**

## TABLE OF INFORMATION DEVELOPED FOR 2012

| CONSTANTS AND CONVERSION FACTORS | | | |
|---|---|---|---|
| Proton mass, | $m_p = 1.67 \times 10^{-27}$ kg | Electron charge magnitude, | $e = 1.60 \times 10^{-19}$ C |
| Neutron mass, | $m_n = 1.67 \times 10^{-27}$ kg | 1 electron volt, | $1 \text{ eV} = 1.60 \times 10^{-19}$ J |
| Electron mass, | $m_e = 9.11 \times 10^{-31}$ kg | Speed of light, | $c = 3.00 \times 10^{8}$ m/s |
| Avogadro's number, | $N_0 = 6.02 \times 10^{23}$ mol$^{-1}$ | Universal gravitational constant, | $G = 6.67 \times 10^{-11}$ m$^3$/kg•s$^2$ |
| Universal gas constant, | $R = 8.31$ J/(mol•K) | Acceleration due to gravity at Earth's surface, | $g = 9.8$ m/s$^2$ |
| Boltzmann's constant, | $k_B = 1.38 \times 10^{-23}$ J/K | | |

| | |
|---|---|
| 1 unified atomic mass unit, | $1 \text{ u} = 1.66 \times 10^{-27} \text{ kg} = 931 \text{ MeV}/c^2$ |
| Planck's constant, | $h = 6.63 \times 10^{-34} \text{ J•s} = 4.14 \times 10^{-15} \text{ eV•s}$ |
| | $hc = 1.99 \times 10^{-25} \text{ J•m} = 1.24 \times 10^{3} \text{ eV•nm}$ |
| Vacuum permittivity, | $\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{N•m}^2$ |
| Coulomb's law constant, | $k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9} \text{ N•m}^2/\text{C}^2$ |
| Vacuum permeability, | $\mu_0 = 4\pi \times 10^{-7}$ (T•m)/A |
| Magnetic constant, | $k' = \mu_0/4\pi = 1 \times 10^{-7}$ (T•m)/A |
| 1 atmosphere pressure, | $1 \text{ atm} = 1.0 \times 10^{5} \text{ N/m}^2 = 1.0 \times 10^{5} \text{ Pa}$ |

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

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

| $\theta$ | $0^\circ$ | $30^\circ$ | $37^\circ$ | $45^\circ$ | $53^\circ$ | $60^\circ$ | $90^\circ$ |
|---|---|---|---|---|---|---|---|
| $\sin\theta$ | 0 | $1/2$ | $3/5$ | $\sqrt{2}/2$ | $4/5$ | $\sqrt{3}/2$ | 1 |
| $\cos\theta$ | 1 | $\sqrt{3}/2$ | $4/5$ | $\sqrt{2}/2$ | $3/5$ | $1/2$ | 0 |
| $\tan\theta$ | 0 | $\sqrt{3}/3$ | $3/4$ | 1 | $4/3$ | $\sqrt{3}$ | $\infty$ |

The following conventions are used in this exam.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.

II. The direction of any electric current is the direction of flow of positive charge (conventional current).

III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

## ADVANCED PLACEMENT PHYSICS C EQUATIONS DEVELOPED FOR 2012

### MECHANICS

$v = v_0 + at$

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

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

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

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

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

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

$F_{fric} \leq \mu N$

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

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

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

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

$\Delta U_g = mgh$

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

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

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

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

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

$v = r\omega$

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

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

$\omega = \omega_0 + \alpha t$

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

$a$ = acceleration
$F$ = force
$f$ = frequency
$h$ = height
$I$ = rotational inertia
$J$ = impulse
$K$ = kinetic energy
$k$ = spring constant
$\ell$ = length
$L$ = angular momentum
$m$ = mass
$N$ = normal force
$P$ = power
$p$ = momentum
$r$ = radius or distance
$\mathbf{r}$ = position vector
$T$ = period
$t$ = time
$U$ = potential energy
$v$ = velocity or speed
$W$ = work done on a system
$x$ = position
$\mu$ = coefficient of friction
$\theta$ = angle
$\tau$ = torque
$\omega$ = angular speed
$\alpha$ = angular acceleration
$\phi$ = phase angle

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

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

$x = x_{\max}\cos(\omega t + \phi)$

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

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

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

$\mathbf{F}_G = -\frac{Gm_1 m_2}{r^2}\hat{\mathbf{r}}$

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

### ELECTRICITY AND MAGNETISM

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

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

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

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

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

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

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

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

$C_p = \sum_i C_i$

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

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

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

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

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

$I = Nev_d A$

$V = IR$

$R_s = \sum_i R_i$

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

$P = IV$

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

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

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

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

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

$B_s = \mu_0 nI$

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

$\mathcal{E} = \oint \mathbf{E} \cdot d\boldsymbol{\ell} = -\frac{d\phi_m}{dt}$

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

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

## ADVANCED PLACEMENT PHYSICS C EQUATIONS DEVELOPED FOR 2012

### GEOMETRY AND TRIGONOMETRY

Rectangle

$A = bh$

Triangle

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

Circle

$A = \pi r^2$

$C = 2\pi r$

Rectangular Solid

$V = \ell wh$

Cylinder

$V = \pi r^2 \ell$

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

Sphere

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

$S = 4\pi r^2$

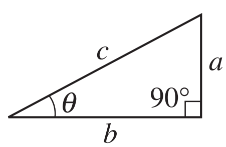
Right Triangle

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

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

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

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




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

### CALCULUS

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

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

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

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

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

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

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

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

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

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

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

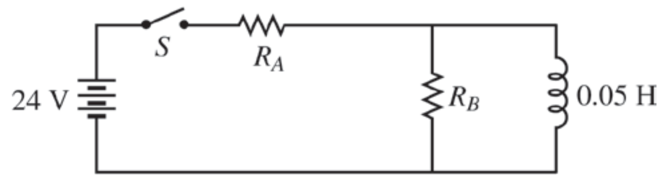
## PHYSICS C: ELECTRICITY AND MAGNETISM

### SECTION II

**Time—45 minutes**

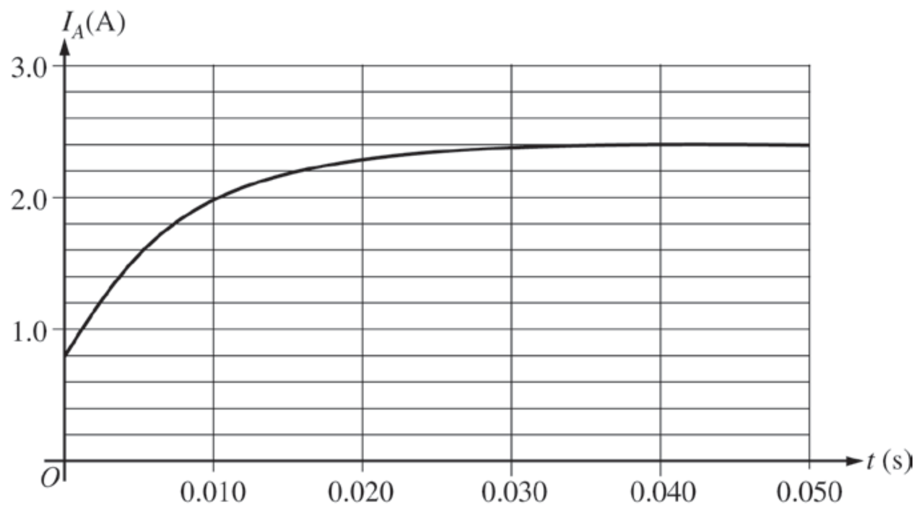
**3 Questions**

**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.




E&M. 1.

Students are given the circuit above in their lab, but they do not know the values of the two resistances $R_A$ and $R_B$. The battery has a terminal voltage of 24 V and the inductor has an inductance of 0.05 H. Assume the internal resistance of both the battery and the inductor to be negligible. The switch $S$ is closed at time $t = 0$. In order to determine the values of the resistances $R_A$ and $R_B$, the students measure the current as a function of time through the resistance $R_A$. The graph of their results is below.




(a) On the circuit diagram above, insert an ammeter to measure the current through $R_A$.

(b) Use the data taken by the students to calculate the value of $R_A$.

(c) Use the data taken by the students to calculate the value of $R_B$.

(d) Calculate the initial rate of change of current in the inductor.

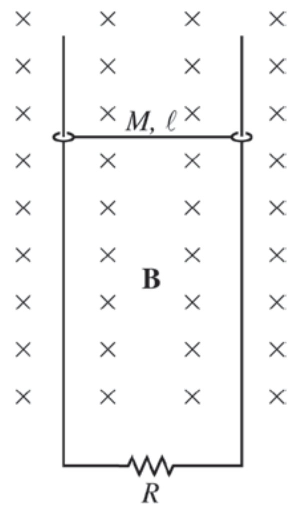
(e) In reality, both the battery and the inductor have nonnegligible internal resistance. Would the true value of $R_A$ be greater than or less than the value you obtained in part (b)?

_____ Greater than ______ Less than

Justify your answer.



GO ON TO THE NEXT PAGE.




E&M. 2.

A bar of mass $M$ and length $\ell$ is connected to two long vertical frictionless rails. The bar and the rails have negligible resistance. They are placed in a uniform magnetic field of strength $B$ directed into the page as shown above. The bottoms of the rails are connected by a resistor of resistance $R$. The bar is released from rest in the position shown. Express all algebraic answers in terms of the given quantities and fundamental constants.

(a) Indicate on the diagram the direction of the current in the resistor.

At a particular time $T$, the bar is falling with speed $v_1$ but has not yet reached the bottom of the magnetic field.

(b) Calculate the power dissipated as heat in the resistor at time $T$.

(c) Calculate the magnitude of the magnetic force on the bar at time $T$ and state its direction.

At some time before leaving the magnetic field, the bar reaches a terminal velocity.

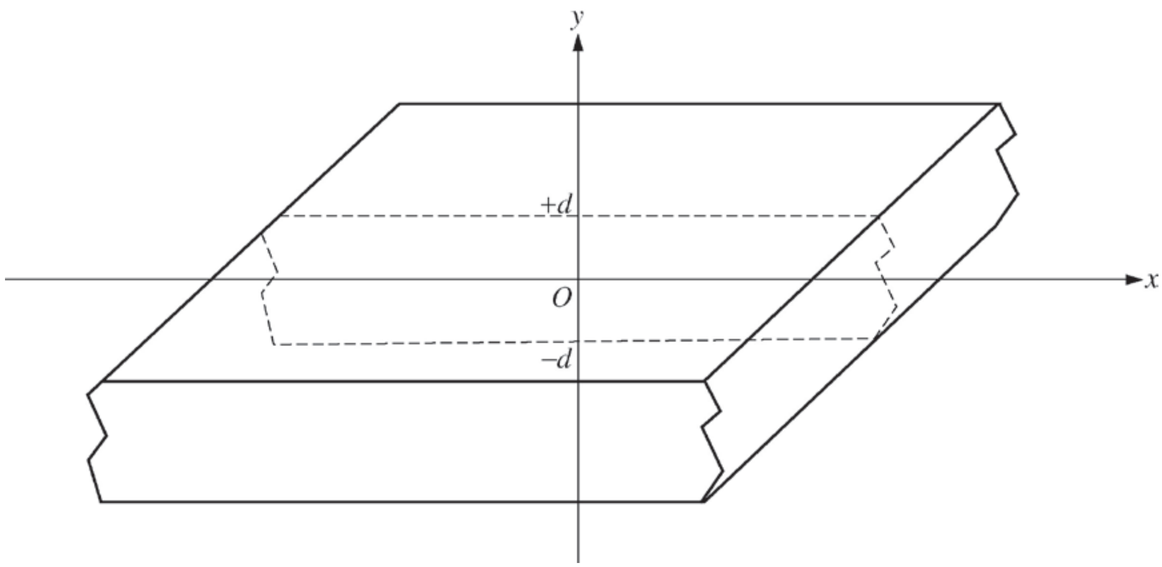
(d) Determine this terminal velocity.

(e) Write, but do NOT solve, the differential equation for the velocity of the falling bar while it is in the magnetic field.

(f) A second identical resistor is placed in parallel with the first. Is the terminal velocity reached by the bar in this case greater than, less than, or equal to that in part (d)?

_______Greater than _______Less than _______Equal to

Justify your answer.



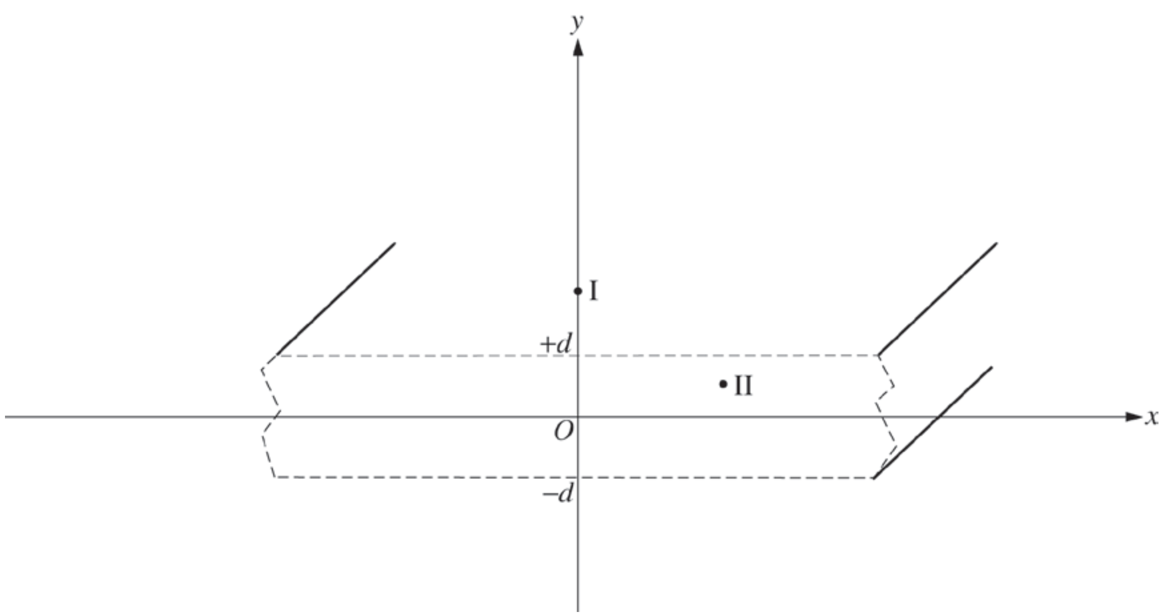

E&M. 3.

A nonconducting slab of infinite length and width and thickness $2d$ is positioned on a coordinate system as shown above. The slab is charged, and the charge per unit volume $\rho$ is given by the expression $\rho(y) = C|y|$, where $-d \leq y \leq +d$ and $C$ is a positive constant.

(a) On the diagram below, do the following.

i. Indicate with vectors the direction of the electric field at point I $(y > d)$ and point II $(0 < y < d)$.

ii. Draw a Gaussian surface that could be used to calculate the magnitude of the electric field at point I.






GO ON TO THE NEXT PAGE.

(b) Using Gauss's law, derive expressions in terms of the given quantities and fundamental constants for the magnitude of the electric field $E$ at the following points.

i. Point I $(y > d)$

ii. Point II $(0 < y < d)$

(c) Calculate the potential difference between the origin and point I .

**STOP**

**END OF EXAM**

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**THE FOLLOWING INSTRUCTIONS APPLY TO THE COVERS OF THE SECTION II BOOKLET.**

- **MAKE SURE YOU HAVE COMPLETED THE IDENTIFICATION INFORMATION AS REQUESTED ON THE FRONT AND BACK COVERS OF THE SECTION II BOOKLET.**
- **CHECK TO SEE THAT YOUR AP NUMBER LABEL APPEARS IN THE BOX(ES) ON THE COVER(S).**
- **MAKE SURE YOU HAVE USED THE SAME SET OF AP NUMBER LABELS ON ALL AP EXAMS YOU HAVE TAKEN THIS YEAR.**

# Multiple-Choice Answer Key

The following contains the answers to the
multiple-choice questions in this exam.

# Answer Key for AP Physics C: Electricity and Magnetism Practice Exam, Section I

Question 1: B

Question 2: B

Question 3: E

Question 4: D

Question 5: A

Question 6: A

Question 7: E

Question 8: B

Question 9: B

Question 10: E

Question 11: A

Question 12: E

Question 13: B

Question 14: E

Question 15: D

Question 16: A

Question 17: E

Question 18: C

Question 19: E

Question 20: E

Question 21: C

Question 22: C

Question 23: C

Question 24: E

Question 25: A

Question 26: E

Question 27: A

Question 28: E

Question 29: D

Question 30: A

Question 31: E

Question 32: D

Question 33: D

Question 34: E

Question 35: D

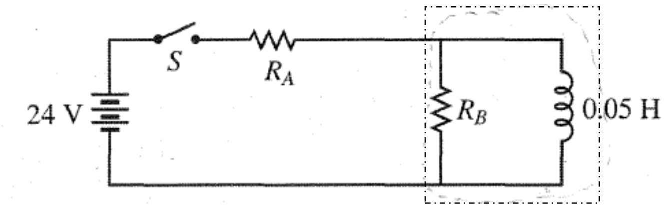
# Free-Response Scoring Guidelines

The following contains the scoring guidelines
for the free-response questions in this exam.

## Question 1

**15 points total** **Distribution of points**

(a) 1 points




For inserting an ammeter in series anywhere in the circuit above EXCEPT inside the dashed box — 1 point

(b) 3 points

At steady state, the potential difference across the inductor and $R_B$ is zero. So $R_A$ can be determined using the 24 V battery potential difference and the steady-state current from the graph.

For a correct use of Ohm's law — 1 point

$V = IR_A$

For correct substitutions into the above equation — 1 point

$$R_A = \frac{V}{I} = \frac{(24\text{ V})}{(2.4\text{ A})}$$

For a correct answer — 1 point

$R_A = 10\ \Omega$

If a student did not use 2.4 A, the substitution point was lost if the value of $I$ was in the range: $2.2 < I < 2.6$. If the value was outside this range, both the substitution and the answer point were lost.

(c) 4 points

For an indication that there is no current through the inductor at time $t = 0$ — 1 point

For correct use of Ohm's law with the resistors in series — 1 point

$V = I(R_A + R_B)$

$V/I = (R_A + R_B)$

$R_B = V/I - R_A$

For correct substitution of the correct initial value of $I$ from the graph and the resistance from part (b) — 1 point

$$R_B = \frac{(24\text{ V})}{(0.8\text{ A})} - (10\ \Omega)$$

For an answer consistent with part (b) — 1 point

$R_B = 20\ \Omega$

**Question 1 (continued)**

| | Distribution of points |
|---|---|
| (d) 5 points | |
| The voltage across the inductor is equal to the voltage across resistor $R_B$ | |
| For using the correct voltage across $R_B$ | 2 points |
| $V_B = I_{Ai}R_B$ | |
| For equating $L\dfrac{dI}{dt}$ and $V_B$ | 1 point |
| $L\dfrac{dI}{dt} = I_{Ai}R_B$ | |
| Solve for $dI/dt$ and substitute correct values | |
| $\dfrac{dI}{dt} = \dfrac{I_{Ai}R_B}{L} = \dfrac{(0.8\ \text{A})(20\ \Omega)}{(0.05\ \text{H})}$ | |
| For a correct answer consistent with part (c) | 1 point |
| For correct units | 1 point |
| $\dfrac{dI}{dt} = 320\ \text{A/s}$ | |
| (e) 2 points | |
| For selecting "Less than" | 1 point |
| For a correct justification | 1 point |
| Example: Since $R_A$ is in series with the battery, then the $10\ \Omega$ calculated value would equal $R_A + R_{battery}$, therefore the true value would be $R_A = 10\ \Omega - R_{battery}$, which is less. | |

## Question 2

**15 points total** **Distribution of points**

(a) 1 point

For any indication that the current in the resistor is to the left (either on the diagram or in the answer space. — 1 point

(b) 4 points

For a correct equation for the power dissipated in a resistor — 1 point

$P = V^2/R$

For relating the potential difference across the resistor to the emf — 1 point

$V = \mathcal{E}$

For a correct expression of the emf in the circuit — 1 point

$\mathcal{E} = -\dfrac{d\phi}{dt} = B\ell v_1$

For a correct answer — 1 point

$P = (B\ell v_1)^2/R$

*Alternate Points*

*Alternate Solution*

*For a correct equation for the power dissipated in a resistor* — *1 point*

$P = I^2R$

*For a correct expression for the emf in the circuit* — *1 point*

$V = \mathcal{E} = -\dfrac{d\phi}{dt} = B\ell v_1$

*For a correct expression for the current in the circuit* — *1 point*

$I = V/R = B\ell v_1/R$

*For a correct answer* — *1 point*

$P = (B\ell v_1)^2/R$

(c) 3 points

For a correct expression for the magnetic force on a current-carrying wire — 1 point

$F_{mag} = I\ell B$

Substituting for the current in the above equation

$F_{mag} = (B\ell v_1/R)\ell B$

For a correct answer — 1 point

$F_{mag} = B^2\ell^2 v_1/R$

For stating the direction of the force is upward or toward the top of the page — 1 point

**Question 2 (continued)**

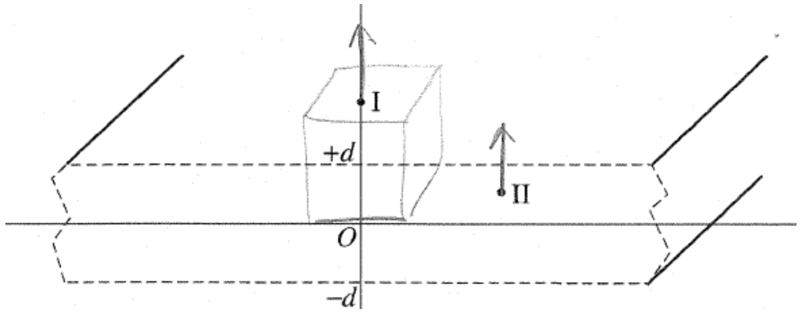
| | **Distribution of points** |
|---|---|
| (d) 2 points | |
| For equating the magnetic force to the gravitational force when equilibrium is reached | 1 point |
| $F_{grav} = F_{mag}$ | |
| $Mg = B^2\ell^2 \upsilon_T / R$ | |
| For an answer consistent with the force from part (c) | 1 point |
| $\upsilon_T = MgR / B^2\ell^2$ | |
| (e) 3 points | |
| Using Newton's 2nd law | |
| $\sum F = ma$ | |
| For correctly substituting the gravitational force into the above equation | 1 point |
| For correctly substituting the magnetic force into the above equation, with a minus sign | 1 point |
| For correctly expressing the acceleration as the derivative of the velocity | 1 point |
| $Mg - \frac{B^2\ell^2}{R}\upsilon = M\frac{d\upsilon}{dt}$ | |
| (f) 2 points | |
| For selecting "Less than" | 1 point |
| For a correct justification | 1 point |
| Example: With a resistor added in parallel, the overall resistance will decrease. If the overall resistance decreases, the terminal velocity will decrease according to the equation in part (d). | |

## Question 3

**15 points total** **Distribution of points**

(a)

i. 2 points




| | |
|---|---|
| For drawing a vector toward the top of the page in the region $y > d$ | 1 point |
| For drawing a vector toward the top of the page in the region $0 < y < d$ | 1 point |

The lengths of the vectors do not matter.

ii. 4 points

| | |
|---|---|
| For drawing <u>any</u> closed surface on the diagram | 1 point |
| For a surface with the top and bottom parallel to the $xz$-plane | 1 point |
| For a surface with sides parallel to the $y$-axis | 1 point |
| For a surface with the bottom at either $y = 0$ or $y = -d$ | 1 point |

(b)

i. 3 points

For a correct expression of Gauss's law — 1 point

$$\oint E \bullet dA = \frac{q_{enc}}{\varepsilon_0}$$

For a correct expression for $q_{enc}$ — 1 point

$$q_{enc} = \int_0^d \rho\, dV = \int_0^d C|y|A dy = \frac{1}{2}CA\Big[y^2\Big]_0^d = \frac{1}{2}CAd^2$$

Substituting the expression for $q_{enc}$ into Gauss's law

$$EA = \frac{\frac{1}{2}CAd^2}{\varepsilon_0}$$

For a correct answer — 1 point

$$E = \frac{Cd^2}{2\varepsilon_0}$$

**Question 3 (continued)**

**Distribution of points**

(b) (continued)

ii. 2 points

For a correct expression for $q_{enc}$ (must show correct limits) — 1 point

$$q_{enc} = \int_0^y C|y|A\,dy = \frac{1}{2}CAy^2$$

For a correct answer — 1 point

$$E = \frac{Cy^2}{2\varepsilon_0}$$

Note: Full credit was awarded for replacing $d$ with $y$ in the answer for part (b)-i, even if the answer in part (b)-i is wrong.

(c) 4 points

For a correct expression relating potential difference to electric field strength — 1 point

$$V = -\int E\,dr \quad \text{or} \quad E = -\frac{dV}{dr} \quad \text{(The minus sign is not required)}$$

For attempting to integrate a correct expression for the electric field strength with the correct limits — 1 point

$$\Delta V = -\int_0^y E(y)\,dy \quad \text{or} \quad \Delta V = \int_y^0 E(y)\,dy \quad \text{(where } y \text{ is the coordinate of point I)}$$

For using a piecewise integration with the answers from parts (b) i and ii — 1 point

$$\Delta V = -\int_0^d \frac{Cy^2}{2\varepsilon_0}dy - \int_d^y \frac{Cd^2}{2\varepsilon_0}dy$$

$$\Delta V = -\frac{C}{6\varepsilon_0}\left[y^3\right]_0^d - \frac{Cd^2}{2\varepsilon_0}[y]_d^y$$

$$\Delta V = -\frac{C}{6\varepsilon_0}\left(d^3 - 0\right) - \frac{Cd^2}{2\varepsilon_0}(y - d)$$

$$\Delta V = -\frac{Cd^3}{6\varepsilon_0} - \frac{Cd^2y}{2\varepsilon_0} + \frac{Cd^3}{2\varepsilon_0}$$

For an answer consistent with the expressions used for $E$ — 1 point

$$\Delta V = \frac{Cd^2}{6\varepsilon_0}(2d - 3y)$$

# Scoring Worksheet

The following provides a worksheet and conversion table used for calculating a composite score of the exam.

# 2013 AP Physics C: Electricity and Magnetism Scoring Worksheet

## Section I: Multiple Choice

____________ × 1.2857 = ________________

Number Correct (out of 35)

Weighted Section I Score (Do not round)

## Section II: Free Response

Question 1 __________ (out of 15) × 1.0000 = __________ (Do not round)

Question 2 __________ (out of 15) × 1.0000 = __________ (Do not round)

Question 3 __________ (out of 15) × 1.0000 = __________ (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 Score Conversion Chart
Physics C: Electricity and Magnetism

| Composite Score Range | AP Score |
|---|---|
| 52-90 | 5 |
| 38-51 | 4 |
| 31-37 | 3 |
| 21-30 | 2 |
| 0-20 | 1 |

# AP Physics C: Electricity and Magnetism

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