AP® Physics C: Electricity and Magnetism Practice Exam

From the 2014 Administration

Contents

Exam Instructions

Student Answer Sheet for the Multiple-Choice Section

Section I: Multiple-Choice Questions

Section II: Free-Response Questions

Multiple-Choice Answer Key

Free-Response Scoring Guidelines

Scoring Worksheet

Note: This publication shows the page numbers that appeared in the ***2013–14 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 *2013–14 AP Exam Instructions* book.

AP® Physics C: Electricity and Magnetism Exam

Regularly Scheduled Exam Date: Monday afternoon, May 12, 2014

Late-Testing Exam Date: Friday afternoon, May 23, 2014

Section I Total Time: 45 min. Section II Total Time: 45 min.

What Proctors Need to Bring to This Exam

- Exam packets
- Answer sheets
- AP Student Packs
- *2013-14 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 45 of the *2013-14 AP Coordinator's Manual*. See pages 42–45 of the *2013-14 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 43 of the *2013-14 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 12, 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 23, 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 *2013-14 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 light 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 with black or dark blue ink 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 or share 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 available 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 available 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 *2013-14 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 2014

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 *2013-14 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

C. YOUR AP NUMBER

D. EXAM DATE — Month | Day

E. EXAM START TIME — AM | PM

F. MULTIPLE-CHOICE BOOKLET SERIAL NUMBER — S

G. ONLINE PROVIDER CODE

H. AP EXAM I AM TAKING USING THIS ANSWER SHEET — Exam Name: | Form: | Form Code:

773898

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

INTERNATIONAL PHONE

J. SCHOOL YOU ATTEND

SCHOOL CODE — School Name | City | State | Country

K. DATE OF BIRTH — Month | Day | Year

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

L. SOCIAL SECURITY NUMBER (Optional)

M. COLLEGE TO RECEIVE YOUR AP SCORE REPORT

COLLEGE CODE — 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

99735-00657• UNLWEB114

Q3779/1-4

PAGE 2

COMPLETE THIS AREA AT EACH EXAM (IF APPLICABLE)

O. 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

P. 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 and Culture, 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). 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.

COMPLETE MARK

EXAMPLES OF INCOMPLETE MARKS

A B C D
A B C D

You must use a No. 2 pencil and marks must be complete. Do not use a mechanical pencil. It is very important that you fill in the entire circle darkly and completely. If you change your response, erase as completely as possible. Incomplete marks or erasures may affect your score.

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

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

(Each grid: − . / / / 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.

Q. 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.)

CITY

ZIP OR POSTAL CODE

COUNTRY CODE

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

R. FOR STUDENTS OUTSIDE THE UNITED STATES ONLY

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

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

S. STUDENT IDENTIFIER (Student ID Number)

T. 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 *2013-14 Bulletin for AP Students and Parents.*

U. STUDENT SEARCH SERVICE®

Colleges and scholarship programs may request your information to inform you of educational opportunities and financial aid.

Would you like us to supply your information?

- Yes
- No

If you don't answer and previously chose to participate in this service, we will continue providing your information.

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

Section I: Multiple-Choice Questions

This is the multiple-choice section of the 2014 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

2014

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 (A) state (B) city (C) country (D) continent (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 4JBP6-S

82

PLACE SEAL HERE
DO NOT seal answer sheet inside

TABLE OF INFORMATION, EFFECTIVE 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,	$N_0 = 6.02 \times 10^{23}$ mol^{-1}
Universal gas constant,	$R = 8.31$ J/(mol•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,	$G = 6.67 \times 10^{-11}$ m^3/kg•s^2
Acceleration due to gravity at Earth's surface,	$g = 9.8$ 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,	$h = 6.63 \times 10^{-34}$ 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,	$k' = \mu_0/4\pi = 1 \times 10^{-7}$ (T•m)/A
1 atmosphere pressure,	$1 \text{ atm} = 1.0 \times 10^5$ 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

θ	$0°$	$30°$	$37°$	$45°$	$53°$	$60°$	$90°$
$\sin\theta$	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	$4/3$	$\sqrt{3}$	∞

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

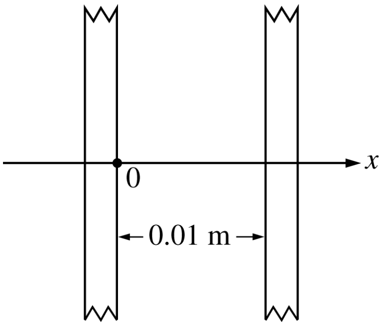
Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

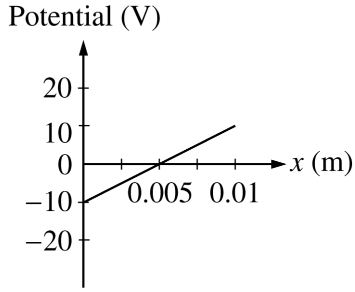
1. Which of the following Gaussian surfaces would be the simplest to use to determine the electric field intensity near a long, straight, charged wire?

   (A) A cylinder whose axis coincides with the wire
   (B) A cylinder whose axis is perpendicular to the wire and passes through the wire
   (C) A sphere with the wire through its center
   (D) A cube with the wire passing through the centers of opposite faces
   (E) A cube with the wire along a diagonal

GO ON TO THE NEXT PAGE.

Questions 2-4





A uniform electric field exists between two parallel plates that are perpendicular to an x-axis and separated by 0.01 m, as shown above on the left. The graph above on the right shows the electric potential between the plates as a function of position x on the x-axis.

2. What is the electric potential energy of an object with a $1.0\ \mu C$ charge located at $x = 0.005$ m?

   (A) $-20\ \mu J$
   (B) $-10\ \mu J$
   (C) Zero
   (D) $10\ \mu J$
   (E) $20\ \mu J$

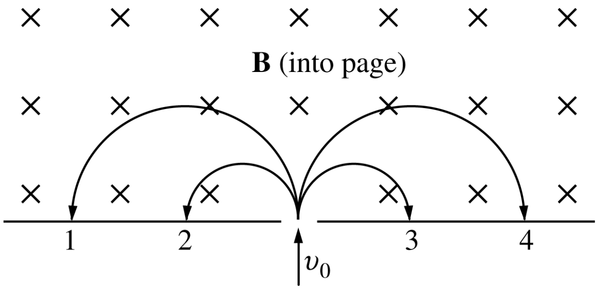
3. What is the magnitude of the electric field between the plates at $x = 0.005$ m?

   (A) Zero
   (B) 0.1 V/m
   (C) 0.2 V/m
   (D) 1000 V/m
   (E) 2000 V/m

4. What is the direction of the electric field between the plates at points on the x-axis?

   (A) To the left at all points
   (B) To the right at all points
   (C) To the left for $x < 0.005$ m and to the right for $x > 0.005$ m
   (D) To the right for $x < 0.005$ m and to the left for $x > 0.005$ m
   (E) It is undefined because the field is zero at all points.

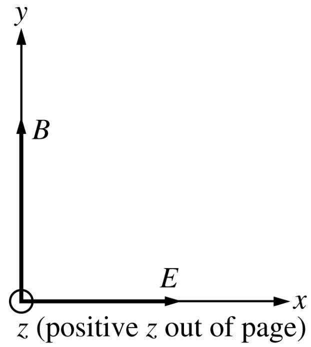
GO ON TO THE NEXT PAGE.



5. Two particles with the same speed v_0 enter a region of uniform magnetic field **B** directed into the page and are initially traveling perpendicular to **B**, as shown above. Particle Y has charge $-Q$ and mass M; particle Z has charge $+Q$ and mass $2M$. Which of the following pairs of paths shown is possible for the subsequent motion of the particles?

	Particle Y $-Q$, M	Particle Z $+Q$, $2M$
(A)	1	4
(B)	2	4
(C)	3	1
(D)	4	1
(E)	4	2

Questions 6-7



A region contains a uniform electric field of strength E in the $+x$-direction and a uniform magnetic field of strength B in the $+y$-direction, relative to the axes shown above. A positively charged particle passes through these two fields in a straight line at a constant speed v.

6. The velocity of the particle is in which direction?

(A) $+y$
(B) $+x$
(C) $-x$
(D) $+z$
(E) $-z$

7. The magnetic field strength B is equal to

(A) E

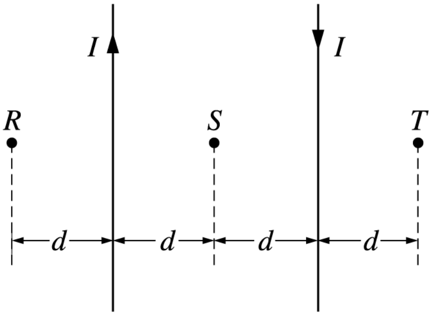
(B) Ev

(C) $\dfrac{E}{v}$

(D) $\dfrac{v}{E}$

(E) Ev^2

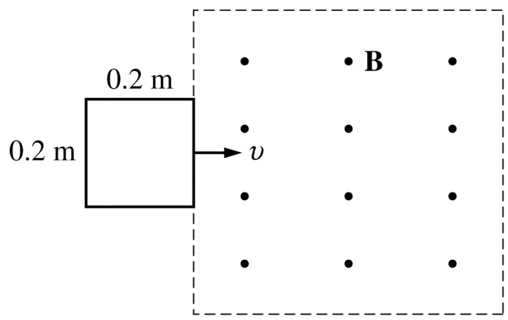
GO ON TO THE NEXT PAGE.

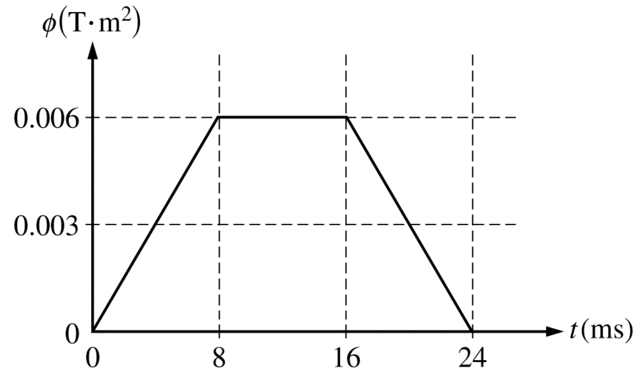


8. Two long, straight, parallel wires in the plane of the page carry equal currents I in opposite directions, as shown above. What are the directions of the resultant magnetic field **B**, if any, at each of the points R, S, and T ?

	$\underline{R}$	$\underline{S}$	$\underline{T}$
(A)	Out of the page	Into the page	Out of the page
(B)	Out of the page	None, $\mathbf{B} = 0$	Out of the page
(C)	Out of the page	None, $\mathbf{B} = 0$	Into the page
(D)	Into the page	None, $\mathbf{B} = 0$	Out of the page
(E)	Into the page	Out of the page	Into the page

Questions 9-10





Note: Figure at left above not drawn to scale.

A square wire loop of side 0.2 m moves with a constant speed of $\upsilon = 25$ m/s through a region containing a magnetic field of strength $B = 0.15$ T, as shown above left. A graph of the magnetic flux ϕ through the loop as a function of time t is shown above right. Time $t = 0$ occurs when the right edge of the loop just begins to enter the field.

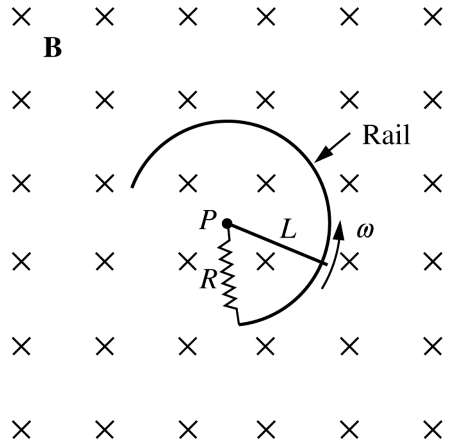
9. What is the magnitude of the induced emf in the wire loop at $t = 4$ ms?

(A) 0 V
(B) 0.50 V
(C) 0.75 V
(D) 3.0 V
(E) 6.0 V

10. What is the total width of the magnetic field through which the loop moves?

(A) 0.1 m
(B) 0.2 m
(C) 0.4 m
(D) 0.6 m
(E) 0.8 m

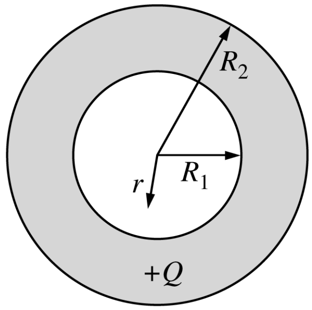
GO ON TO THE NEXT PAGE.



11. A conducting rod of length L is pivoted at point P. The other end slides with negligible friction on a conducting rail in the shape of a circular arc. The plane of the rail and rod is perpendicular to a uniform magnetic field of magnitude B directed into the page, as shown in the figure above. The rod rotates counterclockwise at constant angular velocity ω. Assume that all the resistance of the circuit is contained in the resistor R. Which of the following describes the induced current in the view shown?

(A) It is counterclockwise and constant.
(B) It is counterclockwise and increasing.
(C) It is clockwise and constant.
(D) It is clockwise and increasing.
(E) It is oscillating.

Questions 12-13



A charge $+Q$ is uniformly distributed throughout a nonconducting spherical shell of inner radius R_1 and outer radius R_2, as shown above. The electric field is determined at a distance r from the center of the spherical shell.

12. The electric field for $r < R_1$ is

(A) zero

(B) $\dfrac{1}{4\pi\epsilon_0}\dfrac{Q}{R_1^2}$

(C) $\dfrac{1}{4\pi\epsilon_0}\dfrac{Q}{R_2^2}$

(D) $\dfrac{1}{4\pi\epsilon_0}\dfrac{Q}{(R_2 - R_1)^2}$

(E) $\dfrac{1}{4\pi\epsilon_0}\dfrac{Q}{R_2^2 - R_1^2}$

13. The electric field for $r > R_2$ is

(A) $\dfrac{1}{4\pi\epsilon_0}\dfrac{Q}{R_1^2}$

(B) $\dfrac{1}{4\pi\epsilon_0}\dfrac{Q}{R_2^2}$

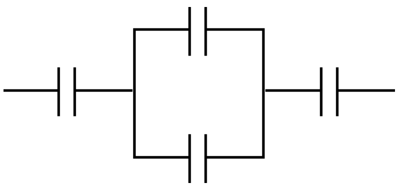
(C) $\dfrac{1}{4\pi\epsilon_0}\dfrac{Q}{r^2}$

(D) $\dfrac{1}{4\pi\epsilon_0}\dfrac{Q}{r^2 - R_2^2}$

(E) $\dfrac{1}{4\pi\epsilon_0}\dfrac{Q}{R_2^2 - R_1^2}$

14. The maximum charge a capacitor can store on one plate is limited by which of the following?

(A) How much charge can physically fit on the conducting plates
(B) The maximum time rate of change of the charge on the other plate
(C) The nonzero energy needed to remove an electron from the conducting plates
(D) The finite value of the capacitance
(E) The electrical discharge when the electric field between the plates becomes too great



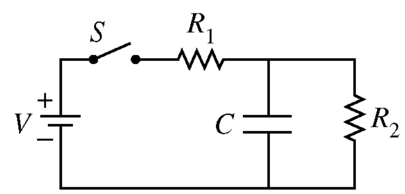
15. The four capacitors in the combination illustrated above each have capacitance C. If all the capacitors are then filled with a dielectric having dielectric constant 2, what is the new total capacitance of the combination?

(A) $(2/5)C$
(B) $(4/5)C$
(C) $(5/4)C$
(D) $(5/2)C$
(E) $5C$

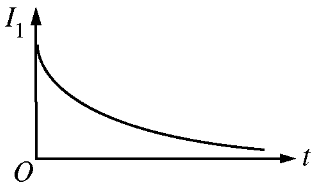
16. Circuit P consists of three identical capacitors connected in parallel with a battery. Circuit S consists of the same three capacitors connected in series with the same battery. When the capacitors are fully charged, what is the ratio of the total energy stored in circuit P to the total energy stored in circuit S ?

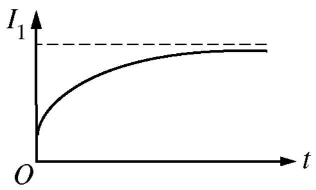
(A) 9
(B) 3
(C) 1
(D) $1/3$
(E) $1/9$

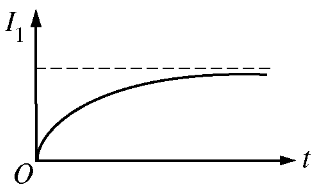
GO ON TO THE NEXT PAGE.

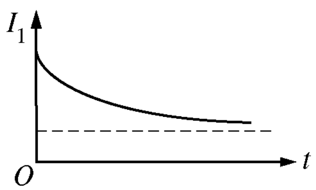


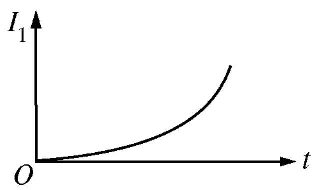
17. Capacitor C and resistors R_1 and R_2 are connected to a battery as illustrated above. The capacitor is initially uncharged. The battery supplies constant voltage V after the switch S is closed at time $t = 0$. Which of the following graphs best represents the current I_1 through the resistor R_1 as a function of t?

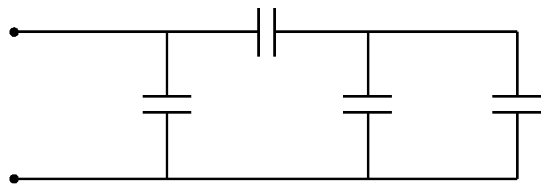
(A) 

(B) 

(C) 

(D) 

(E) 



18. Four identical capacitors of capacitance C are connected as illustrated above. What is their equivalent capacitance?

(A) $3C/5$

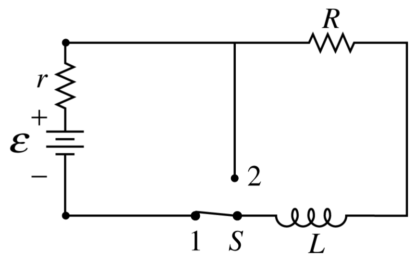
(B) $4C/3$

(C) $5C/3$

(D) $3C$

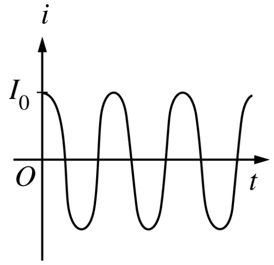
(E) $4C$

GO ON TO THE NEXT PAGE.

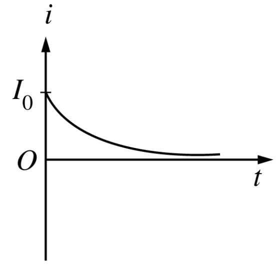


19. The circuit shown above consists of a battery of emf $\mathcal{E}$ and internal resistance r, a resistor R, an inductor L, and a switch S, initially in position 1. After the current i in the inductor reaches its maximum value I_0, S is switched instantaneously from position 1 to position 2 at time $t = 0$. Subsequent variation of i with t is best represented by which of the following graphs?

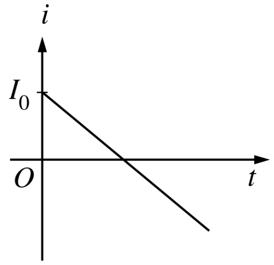
(A)



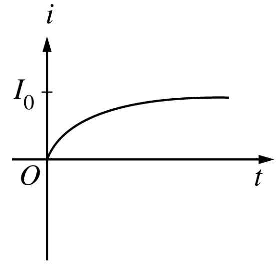
(B)



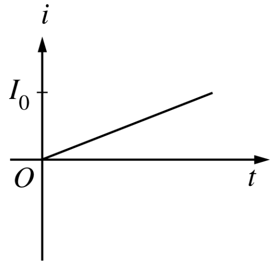
(C)



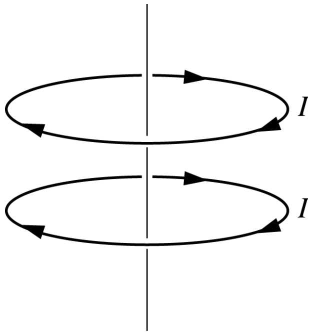
(D)



(E)



GO ON TO THE NEXT PAGE.



20. Two conducting loops that are centered on the same axis carry equal currents I in the same direction as shown in the diagram above. If the current in the upper loop suddenly decreases to zero, what happens to the current in the lower loop according to Lenz's law?

(A) It also decreases to zero.
(B) It decreases, but not to zero.
(C) It does not change.
(D) It increases.
(E) Its direction is reversed.

Questions 21-22

A meter that registers 0.20 mA at full scale has an internal resistance of 500 Ω.

21. To use this meter as an ammeter with a range of 0 to 1 A, one should connect an additional resistance of approximately

(A) 0.10 Ω in parallel with the meter
(B) 0.10 Ω in series with the meter
(C) 500 Ω in series with the meter
(D) 4,500 Ω in series with the meter
(E) 5,000 Ω in parallel with the meter

22. To use this meter as a voltmeter with a range of 0 to 1 V, one should connect an additional resistance of approximately

(A) 0.10 Ω in parallel with the meter
(B) 0.10 Ω in series with the meter
(C) 500 Ω in series with the meter
(D) 4,500 Ω in series with the meter
(E) 5,000 Ω in parallel with the meter

---

23. Copper wire A has twice the length and half the diameter of copper wire B, but carries the same current I. If P is the rate at which energy is dissipated in wire B, what is the rate at which energy is dissipated in wire A?

(A) $\frac{1}{8}P$

(B) $\frac{1}{4}P$

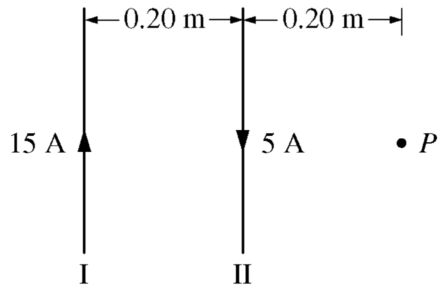
(C) P

(D) $4P$

(E) $8P$

GO ON TO THE NEXT PAGE.

Questions 24-25



Two parallel wires that lie in the plane of the page, as shown above, are a distance of 0.20 m apart. Wire I carries a current of 15 A toward the top of the page, and wire II carries a current of 5 A toward the bottom of the page.

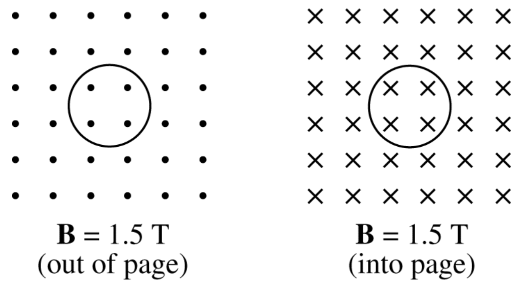
24. What is the magnitude of the net magnetic field at point P, located 0.20 m to the right of wire II ?

    (A) 0.5 μT
    (B) 1.0 μT
    (C) 2.5 μT
    (D) 5.0 μT
    (E) 7.5 μT

25. What is the magnitude of the force per meter that wire I exerts on wire II ?

    (A) 25 μN/m
    (B) 50 μN/m
    (C) 75 μN/m
    (D) 100 μN/m
    (E) 150 μN/m

Questions 26-27



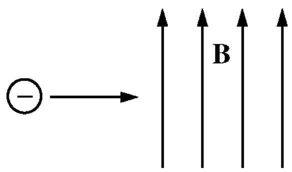
A circular conducting ring of area 0.20 m^2 lies in the plane of the page inside a spatially uniform magnetic field that is perpendicular to the page. The field changes smoothly from 1.5 T directed out of the page, as shown above on the left, to 1.5 T directed into the page, as shown above on the right. The change takes place at a constant rate during a total time interval of 0.6 s.

26. What is the magnitude of the average emf induced during the 0.6 s time interval?

    (A) 0 V
    (B) 0.5 V
    (C) 1.0 V
    (D) 1.5 V
    (E) 2.0 V

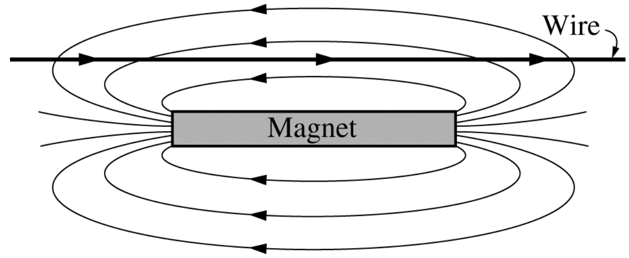
27. When viewed as shown in the figure, what is the direction of the induced current during the first and second halves of the 0.6 s time interval?

	First Half	Second Half
(A)	Clockwise	Clockwise
(B)	Clockwise	Counterclockwise
(C)	Counterclockwise	Clockwise
(D)	Counterclockwise	Counterclockwise
(E)	Undefined, since the current is zero	Undefined, since the current is zero



28. An electron moving to the right with constant velocity enters a region with a uniform magnetic field **B** directed toward the top of the page, as shown above. In what direction will the electron initially be deflected?

(A) Toward the top of the page
(B) Toward the bottom of the page
(C) Into the page
(D) Out of the page
(E) Toward the left



29. A wire is placed parallel to a bar magnet, as shown above, and carries current to the right. Several magnetic field lines outside the bar magnet are shown. Which of the following correctly describes the net magnetic force and torque on the wire?

	Net Force	Torque
(A)	Toward the top of the page	Zero
(B)	Toward the bottom of the page	Zero
(C)	Toward the right	Nonzero
(D)	Zero	Zero
(E)	Zero	Nonzero

GO ON TO THE NEXT PAGE.

30. Two identical spheres are 10.0 cm apart and carry equal charges that create a force of 4.00×10^{-8} N on each. Their diameters are much smaller than their separation distance. First one sphere is completely discharged. The spheres are then moved together until they touch, and finally they are moved to 5.00 cm apart. The new force between the spheres is

(A) 16.0×10^{-8} N
(B) 8.00×10^{-8} N
(C) 4.00×10^{-8} N
(D) 2.00×10^{-8} N
(E) 1.00×10^{-8} N

31. A positively charged particle is at the origin of an x-axis. The potential difference between the points on the axis at $x = 1.0$ m and $x = 2.0$ m due to the particle is 0.90 V. The value of the charge is most nearly

(A) 1.0×10^{-10} C
(B) 1.3×10^{-10} C
(C) 2.0×10^{-10} C
(D) 3.0×10^{-10} C
(E) 4.0×10^{-10} C

32. If the charge on a parallel-plate capacitor is decreased from 6 pC to 2 pC and the plate separation is increased from 1 mm to 3 mm, the energy stored in the capacitor will change from U_0 to

(A) $U_0/4$
(B) $U_0/3$
(C) $3U_0$
(D) $8U_0$
(E) $27U_0$

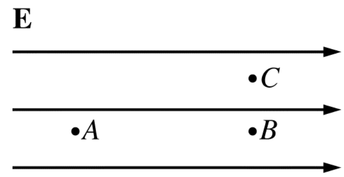
33. A solid metal sphere is in equilibrium and has a net charge Q placed on it. If the sphere is heated so that it expands uniformly without affecting the amount of charge and so that it is still in equilibrium, which of the following will be unaffected by the expansion?

I. The surface charge density
II. The electric potential inside the sphere
III. The electric field inside the sphere

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

34. A conducting spherical shell S has a charge Q distributed over its surface. The total electric flux through any imaginary concentric spherical shell of radius r that encloses S is

(A) inversely proportional to r
(B) inversely proportional to r^2
(C) directly proportional to r
(D) directly proportional to r^2
(E) independent of r



35. The diagram above shows a uniform horizontal electric field and three points that lie in the field. Which of the following is true of the electric potential at the points shown?

I. It is lower at point A than at point B.
II. It is lower at point A than at point C.
III. It is the same at points A and B.
IV. It is the same at points B and C.

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

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.

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 2014 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: Mechanics Exam

SECTION II: Free Response

2014

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 Device
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 4JBP6-S
80

TABLE OF INFORMATION, EFFECTIVE 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,	$\mu_0 = 4\pi \times 10^{-7} \text{ (T•m)/A}$
Magnetic constant,	$k' = \mu_0/4\pi = 1 \times 10^{-7} \text{ (T•m)/A}$
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

θ	$0°$	$30°$	$37°$	$45°$	$53°$	$60°$	$90°$
$\sin\theta$	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	$4/3$	$\sqrt{3}$	∞

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.

MECHANICS

$$v = v_0 + at$$

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

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

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

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

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

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

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

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

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

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

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

$$\Delta U_g = mgh$$

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

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

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

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

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

$$v = r\omega$$

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

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

$$\omega = \omega_0 + \alpha t$$

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

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

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

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

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

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

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

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

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

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

ELECTRICITY AND MAGNETISM

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

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

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

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

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

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

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

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

$$C_p = \sum_i C_i$$

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

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

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

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

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

$$I = Nev_d A$$

$$V = IR$$

$$R_s = \sum_i R_i$$

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

$$P = IV$$

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

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

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

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

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

$$B_s = \mu_0 nI$$

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

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

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

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

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

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

$S = 4\pi r^2$

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

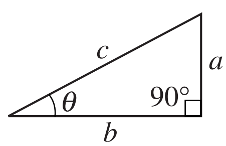
Right Triangle

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

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

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

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



CALCULUS

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

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

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

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

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

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

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

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

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

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

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

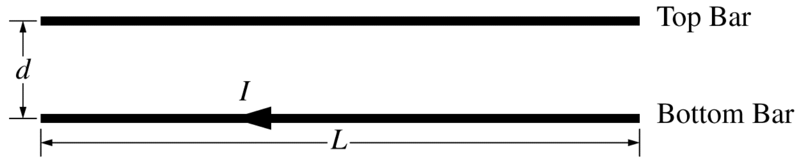
PHYSICS C: ELECTRICITY AND MAGNETISM

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.

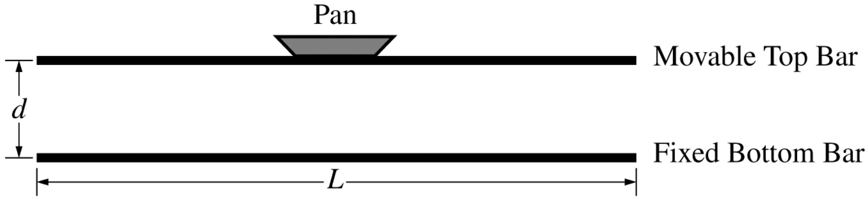
Two metal bars of length L are held a vertical distance d apart $(L >> d)$, as shown in the figure above. Each wire carries a current I, and the wires repel each other. The current is to the left in the bottom metal bar.

(a) In the figure above, draw an arrow indicating the direction of the current in the top bar.

(b) In the figure above, use appropriate symbols to indicate the direction of the magnetic field both above and below the bottom bar due to its current I.

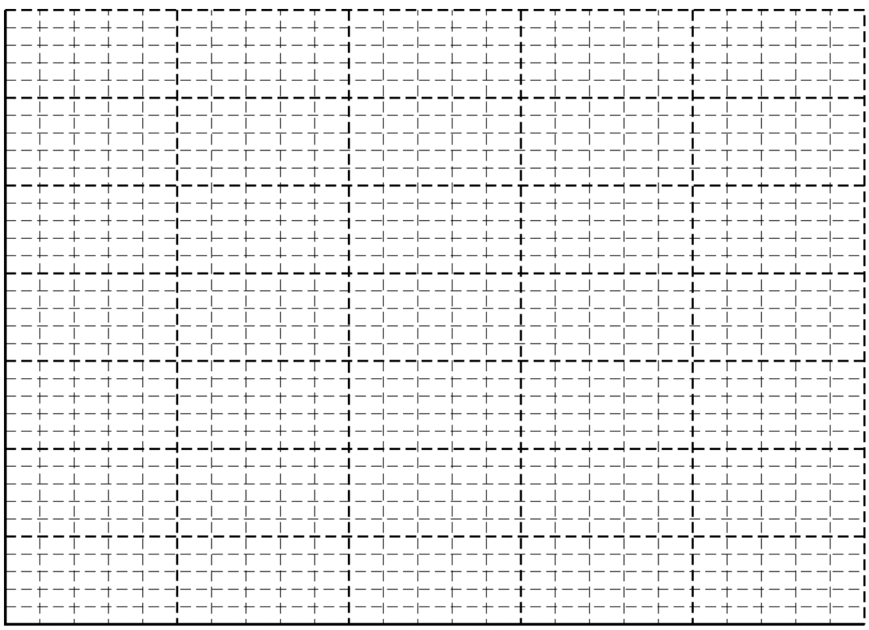
(c) Derive an expression for the magnetic force acting on the top bar in terms of I, L, d, and fundamental constants, as appropriate.

The bars are now used in an experiment, as shown in the figure below. The bottom bar is fixed in place. The top bar is suspended from springs (that are not shown), is free to move up and down, and has a pan attached to it for adding small weights. The top bar is originally horizontal and balanced in the equilibrium position as shown. No current is flowing in the bars. Both bars are part of the same closed circuit (the remainder of the circuit is not shown) and connected to a variable power supply. A small object is placed in the pan on the top bar, forcing it down until it comes close to the bottom bar. The current is turned on and increased until it pushes the top bar back to its original equilibrium position. The process is repeated several times with different objects of known mass, and the current is measured with an ammeter each time. The resulting data are given in the table below.



Weight of Object in Pan (N)	Current (A)	Current^2 (A^2)
1.00×10^{-4}	5.3	27.9
2.00×10^{-4}	7.6	58.4
3.00×10^{-4}	9.6	91.4
4.00×10^{-4}	11.3	128
5.00×10^{-4}	12.5	157

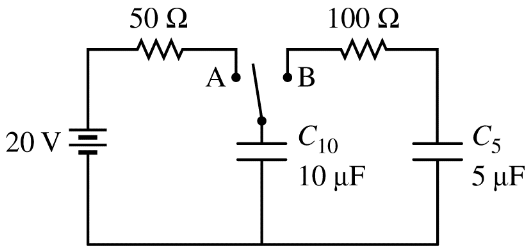
(d) Plot the current squared as a function of the weight of the objects on the grid below. Clearly scale and label all axes and include units as appropriate.



GO ON TO THE NEXT PAGE.

(e) Draw a straight line that best represents the data points and write the equation of the line.

(f) The length of the bars L is 10.2 cm. The center-to-center distance d between the bars is 6.24 mm. Using the equation of the line determined in part (e), calculate a numerical value for the vacuum permeability μ_0.



E&M 2.

In the circuit above, the two capacitors are initially uncharged and the switch is initially open. At time $t = 0$ the switch is moved to position A.

(a) Calculate the current in each of the two resistors immediately after the switch is moved to position A.

i. Current in the 50 Ω resistor

ii. Current in the 100 Ω resistor

(b)

i. Determine the amount of charge stored on the bottom plate of the 10 μF capacitor a long time after the switch is moved to position A.

ii. Indicate the sign of the charge on the bottom plate of the 10 μF capacitor.

____ Positive ____ Negative

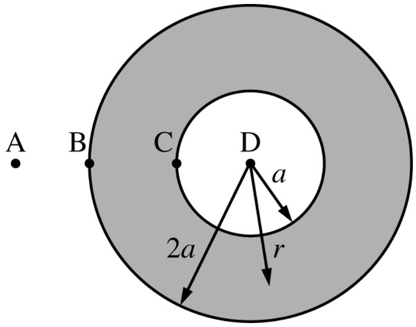
Some time later, the switch is moved to position B.

(c) On the axes below, sketch a graph of the current I in the $100\ \Omega$ resistor as a function of time t after the switch is moved to position B. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.

(d) Calculate the amount of charge on each capacitor a long time after the switch has been moved to position B.

(e) Calculate the total energy dissipated in the $100\ \Omega$ resistor after the switch is moved to position B.

GO ON TO THE NEXT PAGE.



E&M 3.

A spherical insulating shell of radius $2a$ has a hollow cavity of radius a, as shown in the figure above. The charge density in the shell for $a < r < 2a$ varies according to the expression $\rho = br^2$, where b is a positive constant and r is the distance from the center of the shell. Express all algebraic answers to the following in terms of a, b, r, and fundamental constants, as appropriate.

(a) Derive an expression for the total charge on the shell.

(b) Using Gauss's law, derive an expression for the magnitude of the electric field in each of the following regions.

i. $r > 2a$

ii. $r < a$

(c) Derive an expression for the electric potential at the outer surface of the shell, where $r = 2a$. Assume the potential to be zero at $r = \infty$.

(d) Consider the four points A, B, C, and D labeled in the diagram. Rank the four points from highest to lowest based on the electric potential at each point (highest = 1). If two points have the same electric potential, give them the same ranking.

____ A ____ B ____ C ____ D

Justify your rankings.

THIS PAGE MAY BE USED FOR SCRATCH WORK.

STOP

END OF EXAM

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: A
Question 2: C
Question 3: E
Question 4: A
Question 5: C
Question 6: D
Question 7: C
Question 8: A
Question 9: C
Question 10: C
Question 11: A
Question 12: A
Question 13: C
Question 14: E
Question 15: B
Question 16: A
Question 17: D
Question 18: C
Question 19: B
Question 20: D
Question 21: A
Question 22: D
Question 23: E
Question 24: C
Question 25: C
Question 26: C
Question 27: D
Question 28: C
Question 29: E
Question 30: C
Question 31: C
Question 32: B
Question 33: C
Question 34: E
Question 35: C

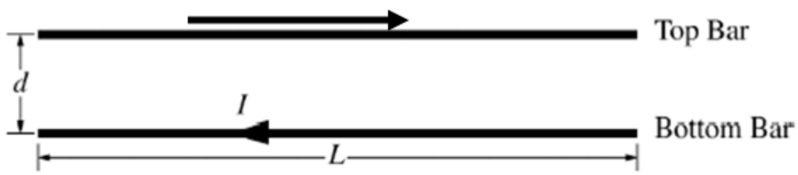
Free-Response Scoring Guidelines

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

Question 1

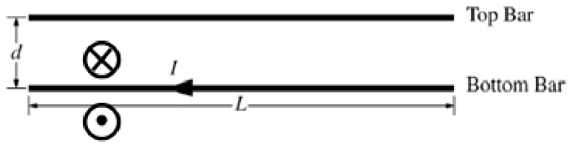
15 points total | **Distribution of points**

(a) 1 point

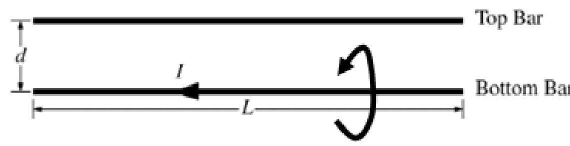


For an arrow indicating that the current must be to the right in the top bar — 1 point

(b) 2 points



or



For a circle with a dot indicating that the magnetic field is out of the page below the bar as shown in the figure above left — 1 point

For a circle with an X indicating that the magnetic field is into the page above the bar as shown in the figure above left — 1 point

OR

2 points for an arc indicating the magnetic field is out of the page below the bar and into the page above the bar as shown in the figure above right

(c) 3 points

For using a correct expression for the magnetic force — 1 point

$F = ILB$

For substituting a correct expression for the magnetic field into the above equation — 1 point

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

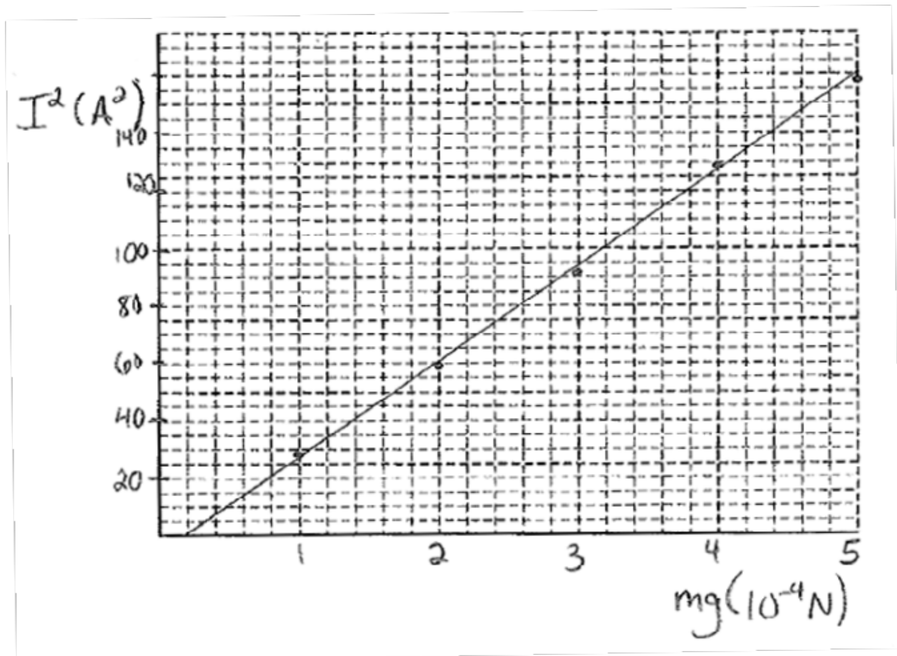
For a correct answer — 1 point

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

Question 1 (continued)

Distribution of points

(d) 3 points



For labeling both axes with correct variable and units — 1 point

For choosing a proper scale for both axes that use at least half the grid — 1 point

For correctly plotting the data points — 1 point

(e) 3 points

For a best-fit straight line on the graph in part (b) — 1 point

For calculating the slope using points on the line — 1 point

$$\text{slope} = \frac{145 - 35}{(4.6 - 1.2) \times 10^{-4}} = 3.24 \times 10^5 \text{ A}^2/\text{N}$$

For an equation of a line consistent with the graph — 1 point

$$y - 0 = \left(3.24 \times 10^5\right)\left(x - 2 \times 10^{-4}\right)$$

$$I^2 = \left(3.24 \times 10^5 \ \text{A}^2/\text{N}\right) mg - 6.48 \text{ A}^2$$

Question 1 (continued)

Distribution of points

(f) 3 points

For setting the weight equal to the magnetic force — 1 point

$F_{net} = 0$

$$mg = \frac{\mu_0 I^2 L}{2\pi d}$$

1 point

For correctly substituting the slope and given values into the above equation

$$\mu_0 = \frac{2\pi d m g}{I^2 L} = \frac{2\pi d}{L}\left(\frac{mg}{I^2}\right)$$

$$\mu_0 = \frac{(2\pi)(0.00624\ \text{m})}{(0.102\ \text{m})\left(3.24\times10^5\ \text{A}^2/\text{N}\right)}$$

1 point

For an answer consistent with the slope from part (e)

$\mu_0 = 1.19\times10^{-6}\ \text{T}\bullet\text{m/A}$

Question 2

15 points total | **Distribution of points**

(a)

i. 2 points

For using Ohm's law — 1 point

$I = \dfrac{V}{R} = \dfrac{(20\ \text{V})}{(50\ \text{W})}$

For a correct answer with units — 1 point

$I = 0.40\ \text{A}$

ii. 1 point

For a correct answer — 1 point

$I = 0$

(b)

i. 2 points

For using the equation for the charge stored in a capacitor — 1 point

$Q = CV = (10\ \mu\text{F})(20\ \text{V})$

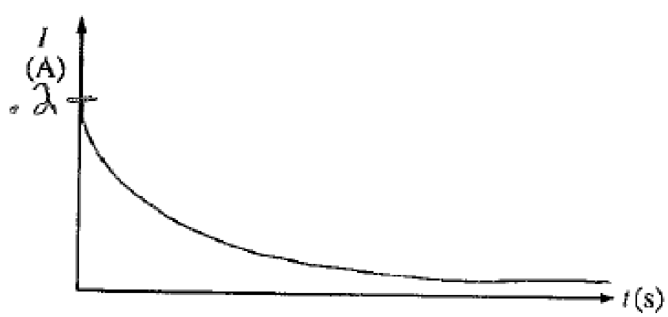
For an answer with units — 1 point

$Q = 2.0 \times 10^{-4}\ \text{C}$

ii. 1 point

For selecting "Negative" — 1 point

(c) 2 points



For indicating the correct maximum current — 1 point

For a curve that is concave up and is asymptotic to the horizontal axis — 1 point

Question 2 (continued)

Distribution of points

(d) 4 points

For a correct expression for the conservation of charge — 1 point

$Q_{tot} = Q_{10} + Q_5$

For setting the potential difference across the two capacitor equal to each other — 1 point

$V_{10} = V_5$

$\dfrac{Q_{10}}{C_{10}} = \dfrac{Q_5}{C_5}$

$\dfrac{Q_{10}}{10\ \mu\text{F}} = \dfrac{Q_5}{5\ \mu\text{F}}$

$Q_{10} = 2Q_5$

Substituting the total charge into the first equation, and eliminating Q_{10}

$2.0 \times 10^{-4}\ \text{C} = 2Q_5 + Q_5 = 3Q_5$

For a correct answer for the $5\ \mu\text{F}$ capacitor — 1 point

$Q_5 = 6.7 \times 10^{-5}\ \text{C}$

Substituting the total charge and the value of Q_5 into the first equation

$Q_{10} = Q_{tot} + Q_5 = 2.0 \times 10^{-4}\ \text{F} - 6.7 \times 10^{-5}\ \text{C}$

For a correct answer for the $10\ \mu\text{F}$ capacitor — 1 point

$Q_{10} = 1.33 \times 10^{-4}\ \text{C}$

(e) 3 points

For calculating the total energy stored in both capacitors — 1 point

$$E_f = \frac{Q_{10}^2}{2C_{10}} + \frac{Q_5^2}{2C_5} = \frac{\left(1.33 \times 10^{-4}\ \text{F}\right)^2}{(2)(10\ \mu\text{F})} + \frac{\left(6.7 \times 10^{-5}\ \text{F}\right)^2}{(2)(5\ \mu\text{F})} = 0.00133\ \text{J}$$

For setting the energy dissipated in the resistor equal to the difference between the initial and final stored energies in the capacitors — 1 point

$$E_R = E_f - \frac{1}{2}C_{10}V^2 = (0.00133\ \text{J}) - \left(\frac{1}{2}\right)(10\ \mu\text{F})(20\ \text{V})^2$$

For a correct answer — 1 point

$E_R = 6.7 \times 10^{-4}\ \text{J}$

AP® PHYSICS C - ELECTRICITY AND MAGNETISM
2014 SCORING GUIDELINES

Question 3

15 points total **Distribution of points**

(a) 5 points

For expressing the charge as an integral of the charge density	1 point
$q = \int \rho dV$	
For a correct expression of the volume element	1 point
$dV = 4\pi r^2 dr$	
For correctly substituting into the integral	1 point
$q = \int br^2 \left(4\pi r^2\right) dr$	
$q = 4\pi b \int r^4 dr$	
For integrating with the correct limits of integration	1 point
$q = 4\pi b \int_{r=a}^{r=2a} r^4 dr$	
$q = 4\pi b \left[\frac{r^5}{5}\right]_{r=a}^{r=2a} = \frac{4\pi b}{5}\left(32a^5 - a^5\right)$	
For a correct answer	1 point
$q = \frac{124}{5}\pi b a^5$	

(b)

i. 2 points

For a correct expression of Gauss's law	1 point
$\frac{q}{\varepsilon_0} = \oint E \bullet dA = E\left(4\pi r^2\right)$	
For correctly substituting the answer from part (a) into Gauss's law	1 point
$\frac{124\pi b a^5}{5\varepsilon_0} = E\left(4\pi r^2\right)$	
Correct answer	
$E = \frac{31ba^5}{5\varepsilon_0 r^2}$	

ii. 1 point

For a correct answer	1 point
$E = 0$	

Question 3 (continued)

Distribution of points

(c) 2 points

For a correct definition of the potential — 1 point

$$V = \frac{Q}{4\pi\varepsilon_0 r}$$

Substituting for the charge and the radius

$$V = \frac{1}{4\pi\varepsilon_0 (2a)}\left(\frac{124\pi b a^5}{5}\right)$$

For an answer consistent with the answer from part (a) — 1 point

$$V = \frac{31ba^4}{10\varepsilon_0}$$

Alternate Solution — *Alternate Points*

For expressing the potential as the integral of the electric field — *1 point*

$$V = \int E \bullet dr$$

Substituting for the electric field

$$V = -\int_{r=\times}^{r=2a} \frac{31ba^5}{5\varepsilon_0 r^2} dr = -\frac{31ba^5}{5\varepsilon_0}\left[-\frac{1}{r}\right]_{r=\times}^{r=2a} = \frac{31ba^5}{5\varepsilon_0}\left(\frac{1}{2a} - \frac{1}{\times}\right)$$

For an answer consistent with the answer from part (a) — *1 point*

$$V = \frac{31ba^4}{10\varepsilon_0}$$

(d) 5 points

For ranking A as the lowest potential — 1 point

For ranking C and D as equal and the highest potential — 1 point

For stating that the electric field is zero inside the shell so the electric potential is constant between C and D — 1 point

For stating or implying that work must be done to move a charge from A to B — 1 point

For stating or implying that work must be done to move a charge from B to C — 1 point

Example:

> The electric field is directed outward from the inner surface of sphere. Therefore, it takes work to move a positive test charge towards the center of the sphere when $r > a$. So it will take work to move a positive test charge from A to B and from B to C. So, B must be at a higher potential than A and C must be at a higher potential than B. Since the electric field is zero inside the sphere, no work is done to move charges inside the sphere. Therefore C and D must be at the same potential.

Scoring Worksheet

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

2014 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 ________ × 1.0000 = ________
(out of 15) (Do not round)

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

Question 3 ________ × 1.0000 = ________
(out of 15) (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
53-90	5
41-52	4
35-40	3
26-34	2
0-25	1

AP Physics C: Electricity and Magnetism

The College Board