AP® Physics C: Electricity and Magnetism Practice Exam

From the 2015 Administration

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Contents

Note: This publication shows the page numbers that appeared in the ***2014–15 AP Exam Instructions*** book and in the actual exam. This publication was not repaginated to begin with page 1.

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Exam Instructions

The following contains instructions taken from the *2014–15 AP Exam Instructions* book.

AP® Physics C: Electricity and Magnetism Exam

Regularly Scheduled Exam Date: Monday afternoon, May 11, 2015

Late-Testing Exam Date: Friday afternoon, May 22, 2015

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

Section I
Total Time: 45 minutes
Calculator Allowed
Number of Questions: 35*
Percent of Total Score: 50%
Writing Instrument: Pencil required

**The number of questions may vary slightly depending on the form of the exam.*

Section II
Total Time: 45 minutes
Calculator Allowed
Number of Questions: 3
Percent of Total Score: 50%
Writing Instrument: Pen with black or dark blue ink, or pencil

What Proctors Need to Bring to This Exam

- Exam packets
- Answer sheets
- AP Student Packs
- *2014-15 AP Coordinator's Manual*
- This book — *AP Exam Instructions*
- AP Exam Seating Chart template(s)
- School Code and Home-School/Self-Study Codes
- Extra calculators
- Extra rulers or straightedges
- Pencil sharpener
- Container for students' electronic devices (if needed)
- 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 rulers, straightedges, and four-function, scientific, or graphing calculators for the entire exam (Sections I and II). 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 *2014-15 AP Coordinator's Manual*. See pages 43–46 of the *2014-15 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 44 of the *2014-15 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.**

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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. Remember: You must complete a seating chart for this exam. See pages 279–280 for a seating chart template and instructions. See the *2014-15 AP Coordinator's Manual* for exam seating requirements (pages 48–50, 88).

If you are giving the regularly scheduled exam, say:

It is Monday afternoon, May 11, 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 22, 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 *2014-15 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? . . .

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

Are there any questions? . . .

You will now take the multiple-choice portion of the exam. You should have in front of you the multiple-choice booklet and your answer sheet. 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. . . .

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, straightedges, and calculators may be used for the entire exam. You may place these items on your desk. 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 35 minutes, say:

There are 10 minutes remaining.

After 10 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. Sit quietly while I collect your answer sheets.

Collect an answer sheet from each student. Check that each answer sheet has an AP number label and an AP Exam label. After all answer sheets have been collected, say:

Now you must seal your exam booklet using the white seals you set aside earlier. 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. . . .

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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 <u>last</u> name and the first letter of your <u>first</u> 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? . . .

Rulers, straightedges, and calculators may be used for Section II. Be sure these items are on your desk. . . .

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> **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 sheet 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 __________. 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. Complete an Incident Report and include any exam booklets with extra sheets of paper in an Incident Report return envelope (see page 57 of the *AP Coordinator's Manual* for details). 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 Exam 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 Exam 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.**

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Then say:

You are now dismissed.

All exam materials must be placed 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 *2014-15 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.

Be sure to give the completed seating chart to the AP Coordinator. Schools must retain seating charts for at least six months (unless the state or district requires that they be retained for a longer period of time). Schools should not return any seating charts in their exam shipments unless they are required as part of an Incident Report.

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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 2015

CollegeBoard

AP Number Label
(from Student Pack)

B123456789T

AP Exam Label
(from Section I Booklet)

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 *2014-15 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:

779934

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: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec | Day | Year

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

104246-00657• UNLWEB315

Q3914/1-4

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
2	A B C D E F G H I	5	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
7	A B C D E F G H I		
8	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 for Questions 1 through 120. 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

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

ETS USE ONLY

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

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

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

QUESTIONS 121–126

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

QUESTIONS 131–142

For Students Taking AP Physics 1 or AP Physics 2

Mark two responses per question. You will receive credit only if both correct responses are selected.

131	A B C D	135	A B C D	139	A B C D
132	A B C D	136	A B C D	140	A B C D
133	A B C D	137	A B C D	141	A B C D
134	A B C D	138	A B C D	142	A B C D

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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 *2014-15 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

In the first column, indicate the highest level of education of your parent/guardian. If you have two parents/guardians, indicate the level of education for your other parent/guardian in the second column. In the appropriate column for each parent/guardian, indicate whether this is your mother or female guardian or your father or male guardian.

- Grade school
- Some high school
- High school diploma or equivalent
- Vocational 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

- Mother or female guardian
- Father or male guardian

Section I: Multiple-Choice Questions

This is the multiple-choice section of the 2015 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

2015

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
Calculator 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 and lists of equations that may be helpful are in the booklet. Calculators, 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 4KBP6-S
82

PLACE SEAL HERE
DO NOT seal answer sheet inside

ADVANCED PLACEMENT PHYSICS C TABLE OF INFORMATION

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, $N_0 = 6.02 \times 10^{23} \text{ mol}^{-1}$	Universal gravitational constant, $G = 6.67 \times 10^{-11} \left(\text{N•m}^2\right)/\text{kg}^2$
Universal gas constant, $R = 8.31$ J/(mol•K)	Acceleration due to gravity at Earth's surface, $g = 9.8 \text{ m/s}^2$
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,	$\varepsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\left(\text{N•m}^2\right)$
Coulomb's law constant,	$k = 1/(4\pi\varepsilon_0) = 9.0 \times 10^{9} \left(\text{N•m}^2\right)/\text{C}^2$
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							
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 assumptions are used in this exam.

I. The frame of reference of any problem is inertial unless otherwise stated.
II. The direction of current is the direction in which positive charges would drift.
III. The electric potential is zero at an infinite distance from an isolated point charge.
IV. All batteries and meters are ideal unless otherwise stated.
V. Edge effects for the electric field of a parallel plate capacitor are negligible unless otherwise stated.

ADVANCED PLACEMENT PHYSICS C EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

$x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2$

$v_x^2 = v_{x0}^2 + 2a_x (x - x_0)$

$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$

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

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

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

$|\vec{F}_f| \le \mu |\vec{F}_N|$

$\Delta E = W = \int \vec{F} \cdot d\vec{r}$

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

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

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

$\Delta U_g = mg\Delta h$

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

$\vec{\tau} = \vec{r} \times \vec{F}$

$\vec{\alpha} = \frac{\sum \vec{\tau}}{I} = \frac{\vec{\tau}_{net}}{I}$

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

$x_{cm} = \frac{\sum m_i x_i}{\sum m_i}$

$v = r\omega$

$\vec{L} = \vec{r} \times \vec{p} = I\vec{\omega}$

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

$\omega = \omega_0 + \alpha t$

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

a = acceleration
E = energy
F = force
f = frequency
h = height
I = rotational inertia
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
L = angular momentum
m = mass
P = power
p = momentum
r = radius or distance
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

$\vec{F}_s = -k\Delta \vec{x}$

$U_s = \frac{1}{2} k (\Delta x)^2$

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

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

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

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

$|\vec{F}_G| = \frac{G m_1 m_2}{r^2}$

$U_G = -\frac{G m_1 m_2}{r}$

ELECTRICITY AND MAGNETISM

$|\vec{F}_E| = \frac{1}{4\pi\varepsilon_0} \left| \frac{q_1 q_2}{r^2} \right|$

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

$\oint \vec{E} \cdot d\vec{A} = \frac{Q}{\varepsilon_0}$

$E_x = -\frac{dV}{dx}$

$\Delta V = -\int \vec{E} \cdot d\vec{r}$

$V = \frac{1}{4\pi\varepsilon_0} \sum_i \frac{q_i}{r_i}$

$U_E = qV = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r}$

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

$C = \frac{\kappa \varepsilon_0 A}{d}$

$C_p = \sum_i C_i$

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

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

$U_C = \frac{1}{2} Q\Delta V = \frac{1}{2} C (\Delta V)^2$

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

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

$I = N e v_d A$

$I = \frac{\Delta V}{R}$

$R_s = \sum_i R_i$

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

$P = I\Delta V$

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 = radius or distance
t = time
U = potential or stored energy
V = electric potential
v = velocity or speed
ρ = resistivity
Φ = flux
κ = dielectric constant

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

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

$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I\, d\vec{\ell} \times \hat{r}}{r^2}$

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

$B_s = \mu_0 n I$

$\Phi_B = \int \vec{B} \cdot d\vec{A}$

$\mathcal{E} = \oint \vec{E} \cdot d\vec{\ell} = -\frac{d\Phi_B}{dt}$

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

$U_L = \frac{1}{2} L I^2$

GEOMETRY AND TRIGONOMETRY

Rectangle

$A = bh$

Triangle

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

Circle

$A = \pi r^2$

$C = 2\pi r$

$s = r\theta$

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

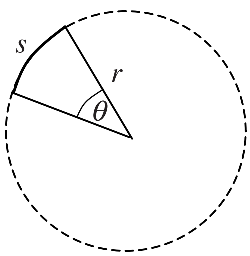
$a^2 + b^2 = c^2$

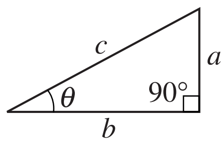
$\sin\theta = \frac{a}{c}$

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

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

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





CALCULUS

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

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

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

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

$$\frac{d}{dx}[\sin(ax)] = a\cos(ax)$$

$$\frac{d}{dx}[\cos(ax)] = -a\sin(ax)$$

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

$$\int e^{ax}\,dx = \frac{1}{a}e^{ax}$$

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

$$\int \cos(ax)\,dx = \frac{1}{a}\sin(ax)$$

$$\int \sin(ax)\,dx = -\frac{1}{a}\cos(ax)$$

VECTOR PRODUCTS

$$\vec{A}\bullet\vec{B} = AB\cos\theta$$

$$\left|\vec{A}\times\vec{B}\right| = AB\sin\theta$$

PHYSICS C: ELECTRICITY AND MAGNETISM

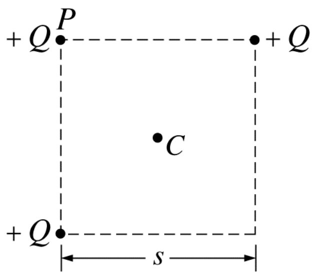
SECTION I

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.

Questions 1-2



Three particles each with charge $+Q$ are placed on three corners of a square, as shown above. The sides of the square have length s. Point C is at the center of the square.

1. What is the direction of the electric field at point C ?

(A)

(B)

(C) 

(D) 

(E) 

2. The particle at corner P is allowed to move while the other two particles are held in place. What is the work done by the electric field as the particle at corner P moves to infinity?

(A) $\dfrac{2kQ^2}{s}$

(B) $\dfrac{2kQ}{s}$

(C) $\dfrac{kQ}{s^2}$

(D) $\dfrac{kQ^2}{s^2}$

(E) $\dfrac{2kQ^2}{s^2}$

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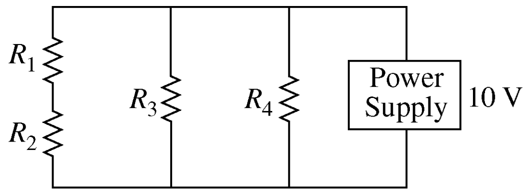
Questions 3-4



Four resistors, all with the same resistance R, are connected as shown above.

3. What is the equivalent resistance of the network?

(A) $4R$
(B) $3R$
(C) $5R/2$
(D) R
(E) $2R/5$

4. If the power supply produces 10 V and the resistance R is $5\ \Omega$, what is the current in resistor R_4?

(A) 15 A
(B) 5 A
(C) 2 A
(D) $1/2$ A
(E) $1/5$ A

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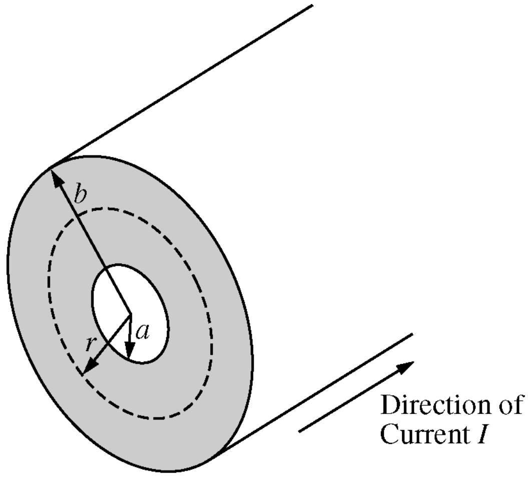
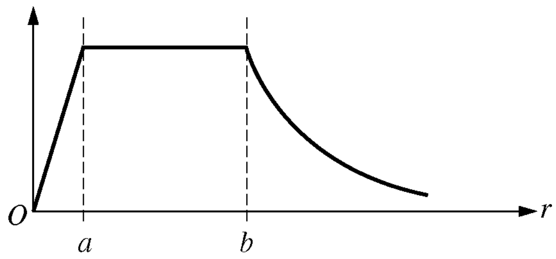
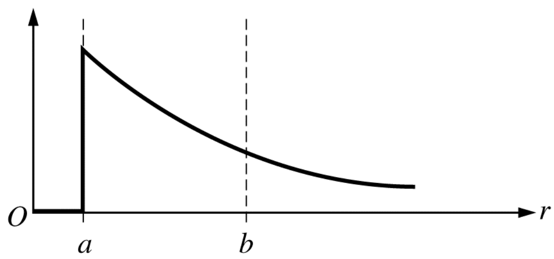
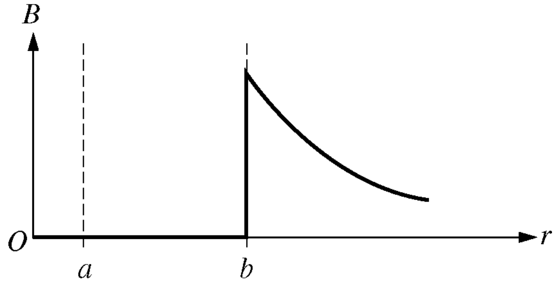
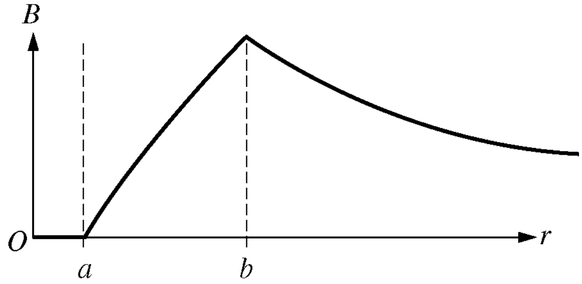


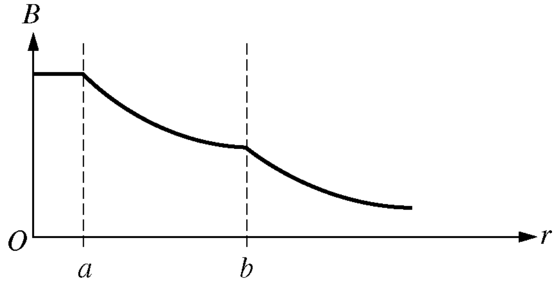
5. A long, cylindrical conductor with inner radius a and outer radius b carries a current I distributed uniformly over its cross section (the shaded region shown above). Which of the following graphs best shows the magnitude of the magnetic field B as a function of the distance r from the axis of the conductor?

(A)


(B)


(C)


(D)


(E)


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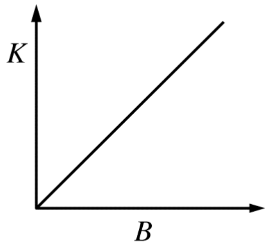
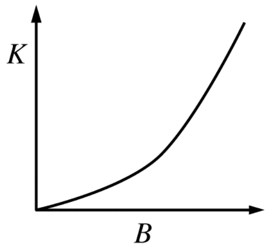
6. A positron (charge $+e$, mass m_e) moves in a circular path of radius R due to a uniform magnetic field of strength B applied perpendicular to the plane of the circle. If B is varied, which of the following best represents a graph of the kinetic energy of the positron as a function of B so that the positron maintains the same radius R ?

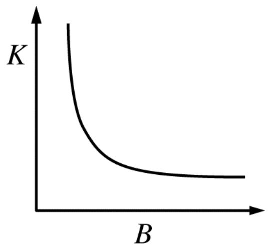
(A)



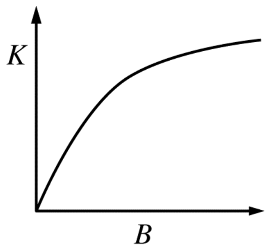
(B)



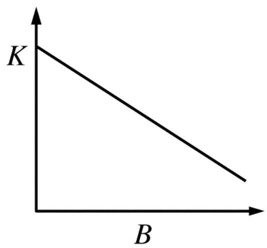
(C)



(D)



(E)



7. The current in a wire is 5 A. What is the value of the closed integral $\oint \vec{B} \bullet d\vec{\ell}$ of the magnetic field along a closed path around the wire?

(A) $\pi \times 10^{-7}$ T•m
(B) $2\pi \times 10^{-7}$ T•m
(C) $10\pi \times 10^{-7}$ T•m
(D) $20\pi \times 10^{-7}$ T•m
(E) $40\pi \times 10^{-7}$ T•m

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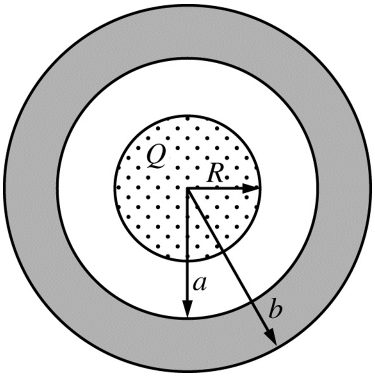
Questions 8-9



An insulated nonconducting sphere of radius R has a charge Q uniformly distributed throughout its volume. It is surrounded by a concentric spherical conducting shell of inner radius a and outer radius b, as shown in the figure above. There is no net charge on the conducting shell. Let E be the electric field magnitude at a distance r from the center of the spheres.

8. Which of the following represents a correct application of Gauss's law for $r > b$?

(A) $0 = E(4\pi)r^2$

(B) $\dfrac{Q}{\epsilon_0} = E(4\pi)r^2$

(C) $\dfrac{Q}{\epsilon_0} = E(4\pi)R^2$

(D) $\dfrac{Qr^3}{\epsilon_0 R^3} = E(4\pi)r^2$

(E) $\dfrac{Qa^3}{\epsilon_0 R^3} = E(4\pi)r^2$

9. Which of the following represents a correct application of Gauss's law for $r < R$?

(A) $0 = E(4\pi)r^2$

(B) $\dfrac{Q}{\epsilon_0} = E(4\pi)r^2$

(C) $\dfrac{Q}{\epsilon_0} = E(4\pi)R^2$

(D) $\dfrac{Qr^3}{\epsilon_0 R^3} = E(4\pi)r^2$

(E) $\dfrac{Qa^3}{\epsilon_0 R^3} = E(4\pi)r^2$

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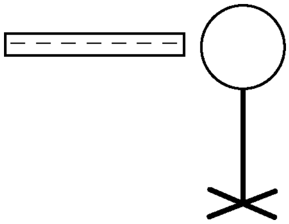
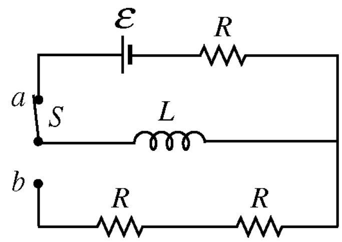


10. A spherical conductor is on an insulating stand, as shown in the figure above. A negatively charged rod is brought close to the sphere but does not touch the sphere. Which of the following describes the resulting charge on the sphere?

(A) Positive
(B) Negative
(C) No net charge, but the sphere is polarized with positive charge on the left side.
(D) No net charge, but the sphere is polarized with negative charge on the left side.
(E) No net charge and no polarization

Questions 11-13



In the circuit above, all of the resistors have the same resistance R. Switch S has been in position a for a very long time.

11. What is the energy stored by the inductor?

(A) Zero

(B) $\dfrac{\mathcal{E}^2}{R}$

(C) $\dfrac{1}{2}L\mathcal{E}^2$

(D) $\dfrac{1}{2}L\dfrac{\mathcal{E}}{R}$

(E) $\dfrac{1}{2}L\dfrac{\mathcal{E}^2}{R^2}$

12. The switch is now moved instantaneously to position b. The voltage across the inductor immediately after the move is

(A) zero
(B) greater than zero but less than $\mathcal{E}$
(C) $\mathcal{E}$
(D) greater than $\mathcal{E}$ but not infinite
(E) infinite

13. The time constant when the switch is in position a is τ_0. How does the time constant when the switch is in position b compare to τ_0?

(A) It is zero.
(B) It is less than τ_0 but greater than zero.
(C) It is equal to τ_0.
(D) It is greater than τ_0 but not infinite.
(E) It is infinite.

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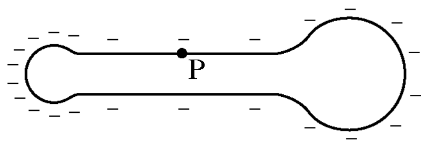
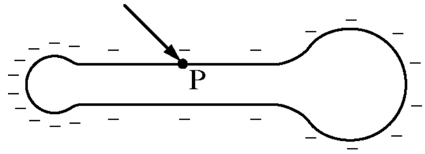
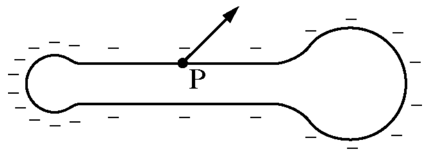
14. If a dielectric is inserted between the plates of a capacitor while the capacitor maintains its connection to a constant voltage source, which of the following is true?

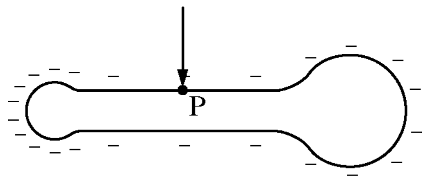
(A) The capacitance of the capacitor is unchanged.
(B) The charge on the capacitor plates increases.
(C) The potential difference across the capacitor increases.
(D) The electric field between the capacitor plates increases.
(E) The electric field between the capacitor plates decreases.

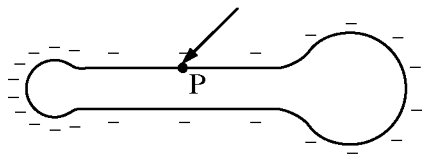


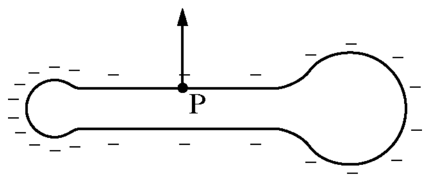
15. The conductor shown above is given a negative charge that spreads over its surface. Which of the following best represents the direction of the electric field at the point P on the cylindrical portion of the conductor?

(A)


(B)


(C)


(D)


(E)


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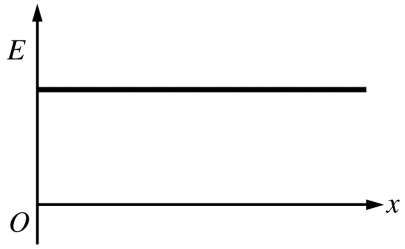
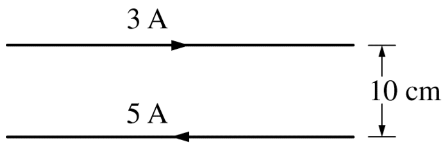


16. The graph above shows the electric field E as a function of x, where x is the distance from a given charge arrangement in an xyz-coordinate system. Which of the following could be the arrangement?

    (A) A positive point charge at $x = 0$
    (B) Positive charges uniformly distributed inside a sphere with $x = 0$ on the sphere's surface
    (C) Positive charges uniformly distributed on the surface of a sphere with $x = 0$ on the sphere's surface
    (D) Positive charges uniformly distributed along the y-axis
    (E) Positive charges uniformly distributed over the yz-plane

17. A negatively charged particle moves in the positive x-direction in a uniform magnetic field directed in the positive y-direction. The particle will experience a force directed in the

    (A) positive z-direction
    (B) negative z-direction
    (C) positive x-direction
    (D) negative x-direction
    (E) positive y-direction



18. Two wires are 10 cm apart, as shown in the figure above. One wire has a current of 3 A to the right, and the other wire has a current of 5 A to the left. What is the magnitude of the magnetic field, in teslas, at the point midway between the wires?

    (A) $\dfrac{20 \times 4\pi \times 10^{-7}}{\pi}$
    (B) $\dfrac{40 \times 4\pi \times 10^{-7}}{\pi}$
    (C) $\dfrac{80 \times 4\pi \times 10^{-7}}{\pi}$
    (D) $\dfrac{100 \times 4\pi \times 10^{-7}}{\pi}$
    (E) $\dfrac{160 \times 4\pi \times 10^{-7}}{\pi}$

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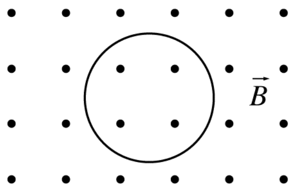
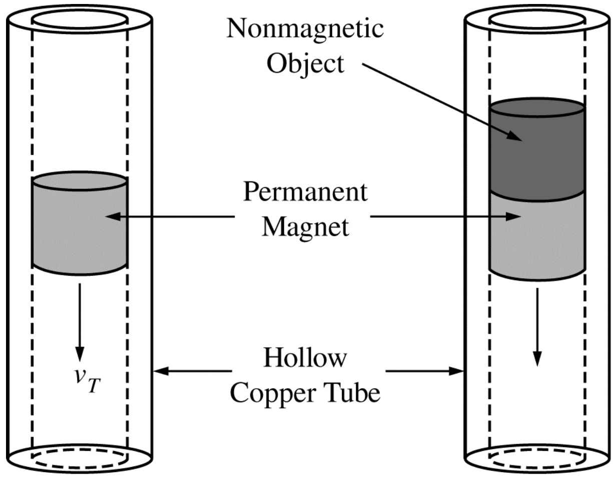


19. A uniform magnetic field $\vec{B}$ is directed out of the page, as represented above. A loop of wire of area $0.8\ m^2$ is in the plane of the page. At a certain instant, the field has a magnitude of 5.0 T and is decreasing at the rate of 0.5 T/s. The magnitude of the induced emf in the wire loop at this instant is most nearly

(A) 0.4 V
(B) 1.6 V
(C) 2.0 V
(D) 4.0 V
(E) 8.0 V



20. A permanent magnet of mass M is dropped down the interior of a hollow cylindrical tube made of copper, as shown at left in the figure above. Friction between the inside of the tube and the magnet is negligible. As the magnet moves downward, an upward magnetic force F_B is induced, and the magnet's velocity quickly reaches a constant terminal value v_T . A nonmagnetic object of mass M is attached to the permanent magnet and the drop is repeated, as shown at right in the figure above. When terminal velocity is reached, how do the new values of F_B and v_T compare with their values without the object?

(A) F_B and v_T are the same.
(B) F_B is larger and v_T is smaller.
(C) F_B is smaller and v_T is larger.
(D) F_B and v_T are both larger.
(E) F_B and v_T are both smaller.

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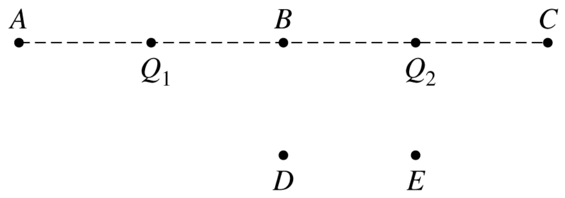
Questions 21-22



Two point charges, $Q_1 = +3\ \mu C$ and $Q_2 = -3\ \mu C$, are situated as shown in the figure above.

21. At which labeled point is the magnitude of the electric field greatest?

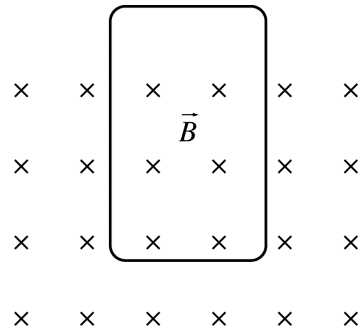
(A) *A*
(B) *B*
(C) *C*
(D) *D*
(E) *E*

22. At which labeled point is the electric potential the lowest?

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

23. A loop of wire with resistance $2\ \Omega$ lies in a magnetic field. The magnetic flux ϕ_m through the loop as a function of time *t* is given by $\phi_m = (2t^2 + 2t)$, where ϕ_m is in tesla•meters squared and *t* is in seconds. What is the current in the loop at $t = 3$ s ?

(A) 6 A
(B) 7 A
(C) 12 A
(D) 14 A
(E) 24 A



24. A conducting loop in the plane of the page is partially inside a uniform magnetic field $\vec{B}$, as shown in the figure above. What is the direction of the net force on the loop as the magnitude of the magnetic field decreases?

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

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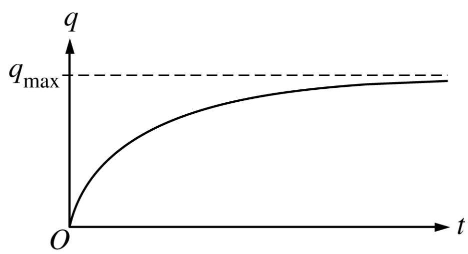
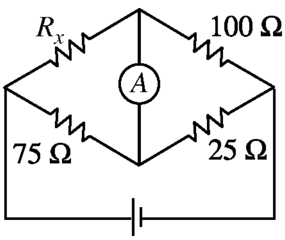


25. A capacitor of capacitance C is connected in series with resistance R and a battery of emf $\mathcal{E}$. The graph above shows the charge q on the capacitor approaching a value q_{max} with increasing time t. What is q_{max} ?

(A) $R/C\mathcal{E}$
(B) $RC/\mathcal{E}$
(C) $\mathcal{E}/RC$
(D) $\mathcal{E}/R$
(E) $C\mathcal{E}$

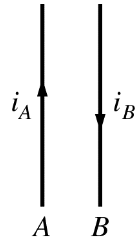
26. A 9 V battery is connected to a $450\ \Omega$ load. If the internal resistance of the battery is negligible, how long will it take for 2 C to pass through the load?

(A) 0.01 s
(B) 0.02 s
(C) 25 s
(D) 50 s
(E) 100 s



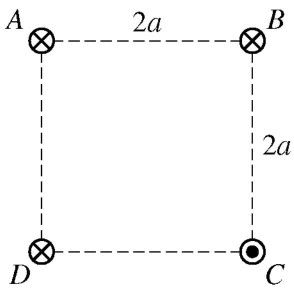
27. In the circuit shown above, the resistances have the values given and there is no current in the ammeter A. What is the value of R_x ?

(A) 25 Ω
(B) 33 Ω
(C) 75 Ω
(D) 100 Ω
(E) 300 Ω



28. Two parallel wires, A and B, have currents in opposite directions, as shown in the figure above. Current i_B is twice as large as i_A. The force on wire A due to current i_B has magnitude F. Which of the following correctly describes the direction and magnitude of the force on wire B due to current i_A ?

	Direction	Magnitude
(A)	To the left	F
(B)	To the left	$2F$
(C)	To the left	$4F$
(D)	To the right	F
(E)	To the right	$2F$



29. Four long, straight wires are arranged at the vertices of a square with sides of length $2a$, as shown in the figure above. Each wire carries a current I. The currents of three of the wires are directed into the page, while the current at point C is directed out of the page. What is the magnetic field at the center of the square?

(A) $\dfrac{\mu_0 I}{\sqrt{2}\pi a}$ toward wire D

(B) $\dfrac{\mu_0 I}{\sqrt{2}\pi a}$ toward wire B

(C) $\dfrac{\mu_0 I}{\sqrt{2}\pi a}$ toward the bottom of the page

(D) $\dfrac{\mu_0 I}{2\pi a}$ toward wire D

(E) $\dfrac{\mu_0 I}{2\pi a}$ toward wire B

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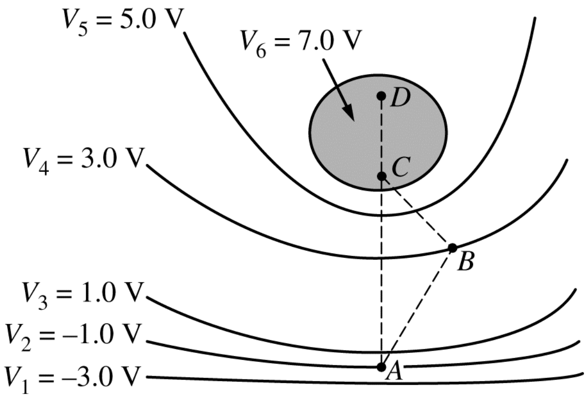
GO ON TO THE NEXT PAGE.

Questions 30-31



Equipotential lines due to an electric field in a certain region of space are illustrated in the figure above. Points *A* and *B* are located on lines V_2 and V_4, respectively, and points *C* and *D* are located within the equipotential region V_6.

30. At which labeled point is the magnitude of the electric field the greatest?

(A) *A*
(B) *B*
(C) *C*
(D) *D*
(E) It is the same at all the points.

31. How much work is required by an external force to move a 2.0 μC charge from rest at point *A* to rest at point *D* via the path *ABCD* ?

(A) 2.0 μJ
(B) 3.0 μJ
(C) 4.0 μJ
(D) 12 μJ
(E) 16 μJ

32. A proton *p* (charge +*e*, mass m_p) collides head-on with a deuteron *d* (charge +*e*, mass $2m_p$). During the collision the particles interact through an electrostatic Coulomb force. Which of the following statements is true about the accelerations $\vec{a}_p$ of the proton and $\vec{a}_d$ of the deuteron during the collision?

(A) $\vec{a}_p = -2\vec{a}_d$
(B) $\vec{a}_p = -\vec{a}_d$
(C) $\vec{a}_p = -\vec{a}_d/2$
(D) $\vec{a}_p = \vec{a}_d$
(E) $\vec{a}_p = 2\vec{a}_d$

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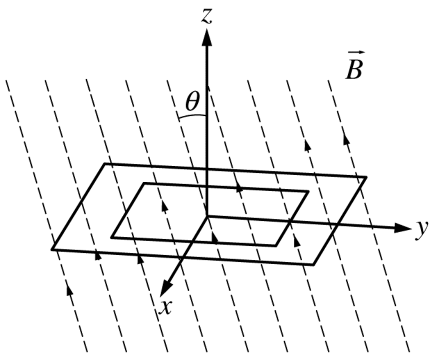

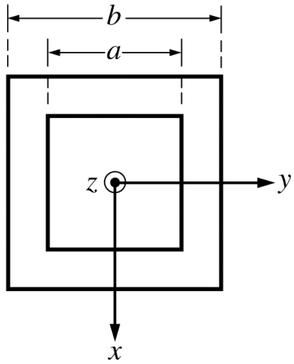

Top View

33. Two square loops of thin metal wire are positioned on the horizontal *xy*-plane in a magnetic field $\vec{B}$ that is directed upward through the loops at an angle θ with the vertical *z*-axis, as shown in the figure above. The small loop has side length *a*. The large loop has side length *b*. The magnetic flux in the space between the loops is

(A) $B(b^2 - a^2)\sin\theta$

(B) $B(b^2 - a^2)\cos\theta$

(C) $B(b - a)^2 \cos\theta$

(D) $Ba^2 \sin\theta$

(E) $Bb^2 \sin\theta$

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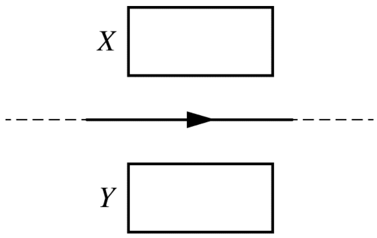
GO ON TO THE NEXT PAGE.

Questions 34-35



Two identical rectangular conducting loops and a very long, straight wire lie in the plane of the page, as shown above. The loops are equal distances from the wire, and there is a current to the right in the wire.

34. If the current in the wire is decreasing, what is the direction of the induced current, if any, in each of the loops?

	Loop *X*	Loop *Y*
(A)	Counterclockwise	Clockwise
(B)	Counterclockwise	Counterclockwise
(C)	Clockwise	Counterclockwise
(D)	Clockwise	Clockwise
(E)	None	None

35. If the current in the wire is constant and the wire is moved toward loop *X*, what is the direction of the induced current, if any, in each of the loops?

	Loop *X*	Loop *Y*
(A)	Counterclockwise	Clockwise
(B)	Counterclockwise	Counterclockwise
(C)	Clockwise	Counterclockwise
(D)	Clockwise	Clockwise
(E)	None	None

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**

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Section II: Free-Response Questions

This is the free-response section of the 2015 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

2015

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 Z-4FBP2-S
82

ADVANCED PLACEMENT PHYSICS C TABLE OF INFORMATION

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, $N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$	Universal gravitational constant, $G = 6.67 \times 10^{-11}\ (\text{N}\cdot\text{m}^2)/\text{kg}^2$
Universal gas constant, $R = 8.31$ J/(mol•K)	Acceleration due to gravity at Earth's surface, $g = 9.8\ \text{m/s}^2$
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,	$h = 6.63 \times 10^{-34}\ \text{J}\cdot\text{s} = 4.14 \times 10^{-15}\ \text{eV}\cdot\text{s}$
	$hc = 1.99 \times 10^{-25}\ \text{J}\cdot\text{m} = 1.24 \times 10^{3}\ \text{eV}\cdot\text{nm}$
Vacuum permittivity,	$\varepsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/(\text{N}\cdot\text{m}^2)$
Coulomb's law constant,	$k = 1/(4\pi\varepsilon_0) = 9.0 \times 10^{9}\ (\text{N}\cdot\text{m}^2)/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}\ (\text{T}\cdot\text{m})/\text{A}$
Magnetic constant,	$k' = \mu_0/(4\pi) = 1 \times 10^{-7}\ (\text{T}\cdot\text{m})/\text{A}$
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							
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 assumptions are used in this exam.

I. The frame of reference of any problem is inertial unless otherwise stated.

II. The direction of current is the direction in which positive charges would drift.

III. The electric potential is zero at an infinite distance from an isolated point charge.

IV. All batteries and meters are ideal unless otherwise stated.

V. Edge effects for the electric field of a parallel plate capacitor are negligible unless otherwise stated.

ADVANCED PLACEMENT PHYSICS C EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

$x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2$

$v_x^2 = v_{x0}^2 + 2a_x (x - x_0)$

$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$

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

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

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

$|\vec{F}_f| \le \mu |\vec{F}_N|$

$\Delta E = W = \int \vec{F} \bullet d\vec{r}$

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

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

$P = \vec{F} \bullet \vec{v}$

$\Delta U_g = mg\Delta h$

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

$\vec{\tau} = \vec{r} \times \vec{F}$

$\vec{\alpha} = \frac{\sum \vec{\tau}}{I} = \frac{\vec{\tau}_{net}}{I}$

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

$x_{cm} = \frac{\sum m_i x_i}{\sum m_i}$

$v = r\omega$

$\vec{L} = \vec{r} \times \vec{p} = I\vec{\omega}$

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

$\omega = \omega_0 + \alpha t$

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

a = acceleration
E = energy
F = force
f = frequency
h = height
I = rotational inertia
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
L = angular momentum
m = mass
P = power
p = momentum
r = radius or distance
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

$\vec{F}_s = -k\Delta\vec{x}$

$U_s = \frac{1}{2} k (\Delta x)^2$

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

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

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

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

$|\vec{F}_G| = \frac{Gm_1m_2}{r^2}$

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

ELECTRICITY AND MAGNETISM

$|\vec{F}_E| = \frac{1}{4\pi\varepsilon_0}\left|\frac{q_1q_2}{r^2}\right|$

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

$\oint \vec{E} \bullet d\vec{A} = \frac{Q}{\varepsilon_0}$

$E_x = -\frac{dV}{dx}$

$\Delta V = -\int \vec{E} \bullet d\vec{r}$

$V = \frac{1}{4\pi\varepsilon_0}\sum_i \frac{q_i}{r_i}$

$U_E = qV = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r}$

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

$C = \frac{\kappa\varepsilon_0 A}{d}$

$C_p = \sum_i C_i$

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

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

$U_C = \frac{1}{2}Q\Delta V = \frac{1}{2}C(\Delta V)^2$

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

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

$I = Nev_d A$

$I = \frac{\Delta V}{R}$

$R_s = \sum_i R_i$

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

$P = I\Delta V$

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 = radius or distance
t = time
U = potential or stored energy
V = electric potential
v = velocity or speed
ρ = resistivity
Φ = flux
κ = dielectric constant

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

$\oint \vec{B} \bullet d\vec{\ell} = \mu_0 I$

$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I\, d\vec{\ell} \times \hat{r}}{r^2}$

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

$B_s = \mu_0 nI$

$\Phi_B = \int \vec{B} \bullet d\vec{A}$

$\mathcal{E} = \oint \vec{E} \bullet d\vec{\ell} = -\frac{d\Phi_B}{dt}$

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

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

GEOMETRY AND TRIGONOMETRY

Rectangle

$A = bh$

Triangle

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

Circle

$A = \pi r^2$

$C = 2\pi r$

$s = r\theta$

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

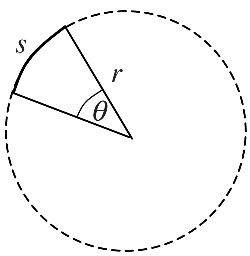
$a^2 + b^2 = c^2$

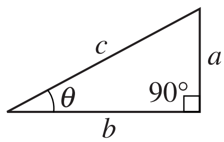
$\sin\theta = \frac{a}{c}$

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

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

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





CALCULUS

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

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

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

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

$$\frac{d}{dx}[\sin(ax)] = a\cos(ax)$$

$$\frac{d}{dx}[\cos(ax)] = -a\sin(ax)$$

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

$$\int e^{ax}\,dx = \frac{1}{a}e^{ax}$$

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

$$\int \cos(ax)\,dx = \frac{1}{a}\sin(ax)$$

$$\int \sin(ax)\,dx = -\frac{1}{a}\cos(ax)$$

VECTOR PRODUCTS

$$\vec{A}\cdot\vec{B} = AB\cos\theta$$

$$\left|\vec{A}\times\vec{B}\right| = AB\sin\theta$$

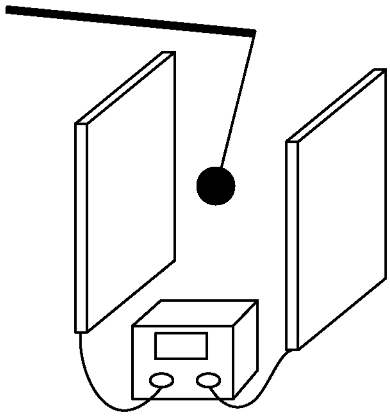
PHYSICS C: ELECTRICITY AND MAGNETISM

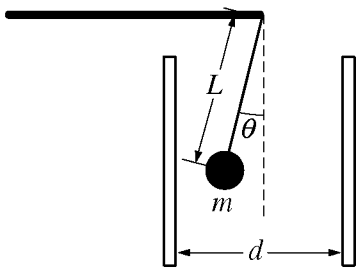
SECTION II

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.



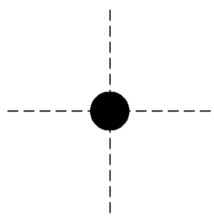


Side View

E&M. 1.

You perform a laboratory experiment to determine the unknown charge on a small conducting ball of mass m using the experimental setup shown in the diagram above. A variable power supply applies a DC voltage to two large parallel plates separated by a distance d, creating a uniform electric field. The charged ball hangs between the plates on an insulated thread of length L and is displaced from its lowest point, coming to equilibrium at an angle θ with the vertical. During the experiment, you measure the angle θ when the voltage indicated on the power supply is V.

(a) On the dot below that represents the conducting ball, draw and label the forces (not components) that act on the conducting ball. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



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GO ON TO THE NEXT PAGE.

(b) Derive an expression that would allow you to calculate the magnitude of the unknown charge on the ball given θ, V, m, d, L, and fundamental constants, as appropriate. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

(c) One way to determine a more accurate value for the magnitude of the charge on the conducting ball in the experiment is to perform multiple trials.

i. What quantity would you vary in this experiment to obtain different values of the angle θ?

ii. What quantities would you plot on a graph to obtain a linear relationship that can be used to determine the magnitude of the charge on the conducting ball?

(d) Describe one difficulty in precisely and accurately determining the angle θ with a protractor, and describe a method to overcome the difficulty.

(e) If the voltage is high enough, the ball touches one of the plates. Describe what happens from the time it touches until you turn off the voltage.

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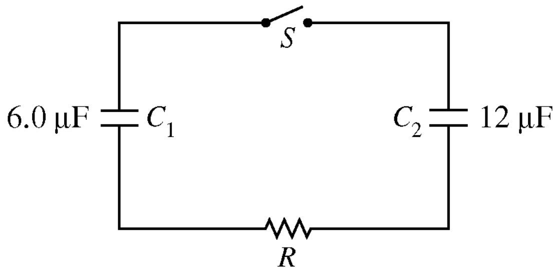

E&M. 2.

A 6.0 μF capacitor, C_1, is initially charged using a 30 V battery. C_1 is then inserted in the circuit represented above with a resistor of resistance R and the 12 μF capacitor C_2, which is initially uncharged. The switch S in the circuit is initially open.

(a) Calculate the charge Q on C_1 before the switch is closed.

The switch is now closed.

(b) Let q_2 be the charge on capacitor C_2 at any time t after the switch is closed. Write, but do NOT solve, a differential equation for the charge q_2 as a function of the time t. Write your equation in terms of the charge Q from part (a), C_1, C_2, R, and fundamental constants, as appropriate.

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(c) Calculate the final charges Q_1 and Q_2 on the two capacitors after equilibrium is reached.

(d) Calculate the energy dissipated in the circuit as the charge is redistributed.

(e) Suppose the resistor was replaced with one of larger resistance and the process was repeated. Would the time it takes capacitor C_2 to reach half its final charge now be longer, the same, or shorter than for the original circuit?

____ Longer ____ The same ____ Shorter

Justify your answer.

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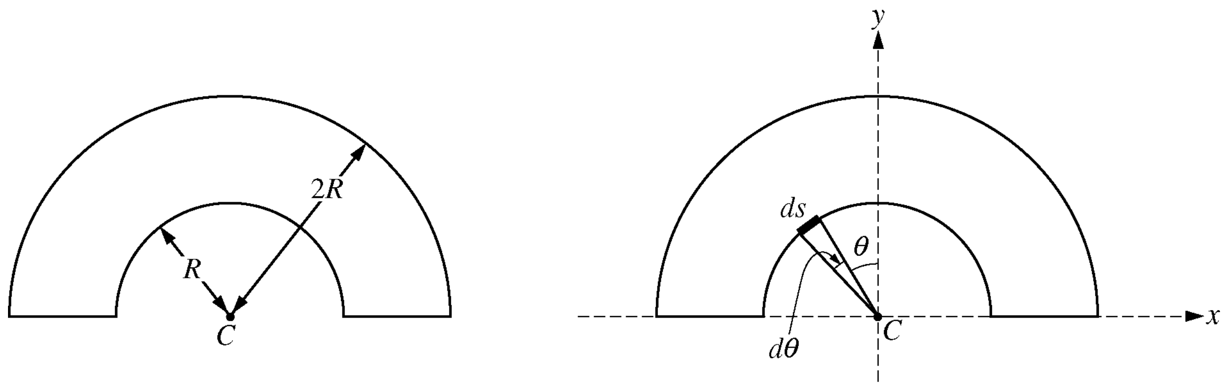

E&M. 3.

A thin nonconducting wire is shaped into a loop containing two concentric semicircular arcs with their centers at point C, as shown above. The wire carries a positive uniform linear charge density λ . Express your answers in parts (a) and (b) in terms of R, λ , θ , and fundamental constants, as appropriate.

(a) Derive an expression for the y-component of the infinitesimally small electric field, dE_y , produced at point C by the charge on the small piece of wire in terms of the infinitesimally small angle $d\theta$ shown in the figure on the right.

(b) Using the expression from part (a), derive an expression for the magnitude of the electric field at point C produced by the entire wire.

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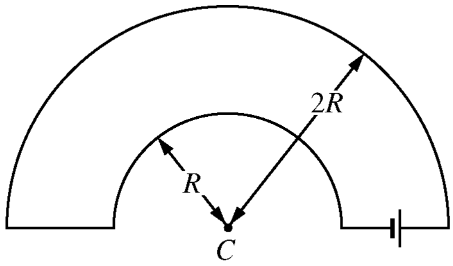
The nonconducting wire is replaced by an uncharged conducting wire with the same size and shape, which has some electrical resistance. A battery is inserted into the loop, as shown below, resulting in a current I in the wire.



(c) Determine the direction of the magnetic field at point C. Explain your reasoning.

(d) Using the Biot-Savart law, derive an expression for the magnitude of the magnetic field B at point C. Express your answers in terms of R, I, and fundamental constants, as appropriate.

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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 ON THE COVER.**
- **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: E

Question 2: A

Question 3: E

Question 4: C

Question 5: D

Question 6: B

Question 7: D

Question 8: B

Question 9: D

Question 10: C

Question 11: E

Question 12: D

Question 13: B

Question 14: B

Question 15: C

Question 16: E

Question 17: B

Question 18: C

Question 19: A

Question 20: D

Question 21: B

Question 22: C

Question 23: B

Question 24: D

Question 25: E

Question 26: E

Question 27: E

Question 28: D

Question 29: A

Question 30: A

Question 31: E

Question 32: A

Question 33: B

Question 34: A

Question 35: D

Free-Response Scoring Guidelines

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

GENERAL NOTES ABOUT 2015 PHYSICS SCORING GUIDELINES

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections—Student Presentation" in the *AP Physics; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based and AP Physics 2: Algebra-Based Course and Exam Description*.

4. The scoring guidelines typically show numerical results using the value $g = 9.8\text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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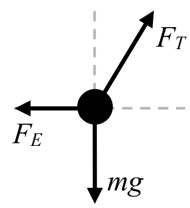
AP® PHYSICS C: ELECTRICITY AND MAGNETISM
2015 SCORING GUIDELINES

Question 1

15 points total | **Distribution of points**

(a) 3 points



For correctly drawing and labeling the tension	1 point
For correctly drawing and labeling the weight of the sphere	1 point
For correctly drawing and labeling the electrostatic force	1 point
One earned point is deducted (up to a maximum of three points) for each extraneous force drawn	

(b) 5 points

For using the correct expression for the force due to the electric field	1 point
$F = qE$	
For relating the voltage and the electric field between parallel plates	1 point
$V = Ed$	
For indicating that the ball is in equilibrium	1 point
$\Sigma\vec{F} = 0$	
For a set of equations that leads to an expression for charge q	1 point
$\Sigma F_x = T\sin\theta - qV/d = 0$	
$\Sigma F_y = T\cos\theta - mg = 0$	
For a correct expression for q	1 point
$q = \dfrac{mgd\tan\theta}{V}$	

(c)

i. 1 point

For choosing either the voltage V or the plate separation d	1 point

ii. 1 point

For selecting variables to graph that are consistent with (c)i and will produce a straight line	1 point
If V is chosen, the graph should be $\tan\theta$ as a function of V or vice versa	
If d is chosen, the graph should be d as a function of $\cot\theta$, $1/d$ as a function of $\tan\theta$ or vice versa	

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Question 1 (continued)

		Distribution of points
(d)	2 points	
	For identifying one difficulty in accurately measuring the angle with a protractor	1 point
	For specifying an appropriate remedy for the difficulty	1 point
(e)	3 points	
	For indicating that the ball's charge will change	1 point
	For indicating that the ball's charge changes polarity	1 point
	For indicating ball will be repelled as a result	1 point

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Question 2

15 points total | **Distribution of points**

(a) 2 points

For substituting values into the equation for the charge on a capacitor — 1 point

$Q = C_1 V = (6\ \mu\text{F})(30\ \text{V})$

For the correct answer — 1 point

$Q = 180\ \mu\text{C} = 1.8 \times 10^{-4}\ \text{C}$

(b) 4 points

For using the loop rule and including the two capacitors and a resistor — 1 point

$V_1 - V_2 - V_R = 0$

For correctly substituting the potential difference across each capacitor — 1 point

$$\frac{q_1}{C_1} - \frac{q_2}{C_2} - iR = 0$$

For correctly using conservation of charge to eliminate the charge on one of the capacitors from the equation — 1 point

$$\frac{Q - q_2}{C_1} - \frac{q_2}{C_2} - iR = 0$$

For expressing the current as the derivative of the charge — 1 point

$$\frac{Q - q_2}{C_1} - \frac{q_2}{C_2} = \frac{dq_2}{dt}R \quad \Rightarrow \quad \frac{Q}{RC_1} - \frac{q_2}{R}\left(\frac{1}{C_1} + \frac{1}{C_2}\right) = \frac{dq_2}{dt}$$

(c) 3 points

For using conservation of charge — 1 point

$Q_1 + Q_2 = 180\ \mu\text{C}$

For recognizing that the potential difference is the same across both capacitors after equilibrium is reached — 1 point

$$V = \frac{Q_1}{C_1} = \frac{Q_2}{C_2}$$

Combining the equations above and solving

$$\frac{180\ \mu\text{C} - Q_2}{6\ \mu\text{F}} = \frac{Q_2}{12\ \mu\text{F}}$$

$2160\ \mu\text{C} - 12Q_2 = 6Q_2$

For a correct answer for the charge on each capacitor — 1 point

$Q_1 = 60\ \mu\text{C}$

$Q_2 = 120\ \mu\text{C}$

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Question 2 (continued)

Distribution of points

(d) 3 points

For recognizing that the energy dissipated is the difference in potential energy before the switch is closed and after the circuit reaches the new equilibrium — 1 point

$\Delta U = U_f - U_i$

For using correct expressions for potential energy of the capacitors — 1 point

$$U_i = \frac{1}{2}C_1V_{1i}^2 = \frac{Q_1{}^2}{2C_1}$$

$$U_f = \frac{Q_1{}^2}{2C_1} + \frac{Q_2{}^2}{2C_2}$$

For correct substitution of values consistent with part (c) — 1 point

$$\Delta U = \left(\frac{(60\ \mu\text{C})^2}{2(6\ \mu\text{F})} + \frac{(120\ \mu\text{C})^2}{2(12\ \mu\text{F})}\right) - \frac{(180\ \mu\text{C})^2}{2(6\ \mu\text{F})} = 9 \times 10^{-4}\ \text{J} - 2.7 \times 10^{-3}\ \text{J}$$

$$\Delta U = -1.8 \times 10^{-3}\ \text{J} = -1800\ \mu\text{J}$$

(e) 2 points

For correctly selecting "Longer" — 1 point

For a correct justification — 1 point

Units 1 point

For correct units on all numerical answers — 1 point

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Question 3

15 points total | **Distribution of points**

(a) 4 points

For a correct expression for the y-component of the field element — 1 point

$dE_y = dE\cos\theta$

For a correct expression for the field due to an element of charge on the wire — 1 point

$$E = \frac{kq}{R^2}$$

$$dE = \frac{k\,dq}{R^2}$$

For expressing the charge element dq in terms of λ, R, and θ — 1 point

$dq = \lambda\,ds$ and $ds = R\,d\theta$ so $dq = \lambda R\,d\theta$

For a correct substitution using the equations above — 1 point

$$dE_y = dE\cos\theta = \left[\frac{k\,dq}{R^2}\right]\cos\theta = \frac{k\,(\lambda R\,d\theta)}{R^2}\cos\theta$$

$$dE_y = \frac{k\lambda\cos\theta}{R}d\theta = \frac{\lambda\cos\theta}{4\pi\varepsilon_0 R}d\theta$$

(b) 5 points

For demonstrating that the x-component of the electric field is zero — 1 point

$\Sigma E_x = 0$

For showing that the net field is due to the two concentric arcs — 1 point

$E = \Sigma E_y = E_{y-inner} + E_{y-outer}$

For using $2R$ for the outer arc — 1 point

$$E = \Sigma E_y = \int \frac{k\lambda\cos\theta}{R}d\theta + \int \frac{k\lambda\cos\theta}{2R}d\theta$$

For integrating with appropriate limits or constant of integration — 1 point

$$E = \int_{-\pi/2}^{\pi/2} \frac{k\lambda\cos\theta}{R}d\theta + \int_{-\pi/2}^{\pi/2} \frac{k\lambda\cos\theta}{2R}d\theta$$

For a correct answer — 1 point

$$E = \frac{3k\lambda}{R} = \frac{3}{4\pi\varepsilon_0}\frac{\lambda}{R}$$

(c) 2 points

For indicating that the magnetic field is into the page — 1 point

For indicating that the field of the inner wire is stronger than the field of the outer wire — 1 point

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Question 3 (continued)

Distribution of points

(d) 4 points

For using the law of Biot-Savart — 1 point

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I\,d\vec{\ell}\times\hat{r}}{r^2}$$

For showing that the net field is due to the two concentric arcs — 1 point

$$\Sigma B = B_{inner} - B_{outer}$$

For using $2R$ for the outer arc — 1 point

$$\Sigma B = \int_{-\pi/2}^{\pi/2}\frac{\mu_0}{4\pi}\frac{I(R\,d\theta)}{R^2} - \int_{-\pi/2}^{\pi/2}\frac{\mu_0}{4\pi}\frac{I(2R\,d\theta)}{(2R)^2}$$

$$\Sigma B = \frac{\mu_0 I}{4R} - \frac{\mu_0 I}{8R}$$

For a correct answer — 1 point

$$\Sigma B = \frac{\mu_0 I}{8R}$$

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Scoring Worksheet

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

2015 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
47-90	5
34-46	4
29-33	3
20-28	2
0-19	1

AP Physics C: Electricity and Magnetism

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