From the 2017 Administration

AP CollegeBoard

Physics C: Electricity and Magnetism

Practice Exam

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Note: This publication shows the page numbers that appeared in the *2016–17 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 *2016–17 AP Exam Instructions* book.

AP® Physics C: Electricity and Magnetism Exam

Regularly Scheduled Exam Date: Monday afternoon, May 8, 2017

Late-Testing Exam Date: Friday afernoon, May 19, 2017

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
- *2016-17 AP Coordinator's Manual*
- This book — *AP Exam Instructions*
- AP Exam Seating Chart template
- 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"

Before Distributing Exams: Check that the title on all exam covers is **Physics C: Electricity and Magnetism**. If there are any exam booklets with a different title, contact the AP coordinator immediately.

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 49 of the *2016-17 AP Coordinator's Manual*. See pages 46–49 of the *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 47 of the *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.

Tables containing equations commonly used in physics are included in each AP Exam booklet, for use during the entire exam. Students are NOT allowed to bring their own copies of the equation tables to the exam room.

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 325–326 for a seating chart template and instructions. See the *2016-17 AP Coordinator's Manual* for exam seating requirements (pages 51–54).

If you are giving the regularly scheduled exam, say:

It is Monday afternoon, May 8, 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 19, 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 *2016-17 Bulletin for AP Students and Parents*.

Look at your exam packet and confirm that the exam title is "AP Physics C: Electricity and Magnetism." Raise your hand if your exam packet contains any title other than "AP Physics C: Electricity and Magnetism" and I will help you.

Once you confirm that all students have the correct exams, say:

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 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 can still 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 of your exam booklet 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 the multiple-choice exam content at any time in any form with anyone, including your teacher and other students. If you disclose the multiple-choice exam content through any means, your AP Exam score will be canceled.

Open your answer sheet to page 2. 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. . . .

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 take an AP number label from your Student Pack and place it 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 a pen with black or dark blue ink, 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, using your pen, 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. . . .

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. . . .

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 question number 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 a question in 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. A single Incident Report may be completed for multiple students per exam subject per administration (regular or late testing) as long as all of the required information is provided. Include all exam booklets with extra sheets of paper in an Incident Report return envelope (see page 62 of the *2016-17 AP Coordinator's Manual* for complete 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 the free-response exam content with anyone unless it is 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 content 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.

Then say:

You are now dismissed.

Post-Exam Tasks

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.

The exam proctor should complete the following tasks if asked to do so by the AP coordinator. Otherwise, the AP coordinator must complete these tasks.

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 *2016-17 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 2017

AP Number Label
(from Student Pack)

123456789

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 exam content. I will seal the multiple-choice booklet when asked to do so, and I will not discuss the exam content 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 *2016-17 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

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

O. 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.

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

792107

SCHOOL USE ONLY

Section Number (1 2 3 4 5 6 7 8 9)

Fee Reduction Granted (1) Option 1 (2) Option 2

113913-00657 • UNLWEB1116

Q4298/1-4

COMPLETE THIS AREA AT EACH EXAM (IF APPLICABLE).

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

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

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

If this answer sheet is for the French Language and Culture, German Language and Culture, Italian Language and Culture, Spanish Language 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

QUESTIONS 131–142

For Students Taking AP Computer Science Principles, 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.

R. YOUR MAILING ADDRESS

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

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

CITY

ZIP OR POSTAL CODE

COUNTRY CODE

STATE

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

V. SEX

- Female
- Male

W. WHICH LANGUAGE DO YOU KNOW BEST?

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

X. RACIAL/ETHNIC GROUP

Please answer both questions about Hispanic origin and about race. For the following questions about your identity, Hispanic origins are not races.

(You may mark all that apply.)

a. Are you of Hispanic, Latino, or Spanish origin?

- No, not of Hispanic, Latino, or Spanish origin
- Yes, Cuban
- Yes, Mexican
- Yes, Puerto Rican
- Yes, another Hispanic, Latino, or Spanish origin

b. What is your race?

- American Indian or Alaska Native
- Asian (including Indian subcontinent and Philippines origin)
- Black or African American (including Africa and Afro-Caribbean origin)
- Native Hawaiian or other Pacific Islander
- White (including Middle Eastern origin)

Y. PARENTAL EDUCATION LEVEL

In the first column, indicate the highest level of education of one parent/guardian, and indicate whether this is your mother/female guardian or father/male guardian. Then, if applicable, indicate the highest level of education of your other parent/guardian in the second column, and indicate whether this is your mother/female guardian or father/male guardian.

	Mother or female guardian
	Father or male guardian
Grade school	Grade school
Some high school	Some high school
High school diploma or equivalent	High school diploma or equivalent
Vocational or trade school	Vocational or trade school
Some college	Some college
Associate or two-year degree	Associate or two-year degree
Bachelor's or four-year degree	Bachelor's or four-year degree
Some graduate or professional school	Some graduate or professional school
Graduate or professional degree	Graduate or professional degree

S. FOR STUDENTS OUTSIDE THE UNITED STATES ONLY

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

Address	City	State or Province	Country	ZIP or Postal Code

T. STUDENT IDENTIFIER (Student ID Number)

U. EMAIL ADDRESS

By providing your email address, you are granting the College Board permission to use your email address in accordance with the policies in the *2016-17 Bulletin for AP Students and Parents*.

Section I: Multiple-Choice Questions

This is the multiple-choice section of the 2017 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 I: Multiple Choice

2017

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.

Form I
Form Code 4NBP4-S

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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, $N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant, $G = 6.67 \times 10^{-11}$ $\left(\text{N}\cdot\text{m}^2\right)/\text{kg}^2$
Universal gas constant, $R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface, $g = 9.8$ 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, $\varepsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\left(\text{N}\cdot\text{m}^2\right)$

Coulomb's law constant, $k = 1/(4\pi\varepsilon_0) = 9.0 \times 10^{9}\ \left(\text{N}\cdot\text{m}^2\right)/\text{C}^2$

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, $1\text{ atm} = 1.0 \times 10^{5}\ \text{N/m}^2 = 1.0 \times 10^{5}$ 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

$v_x = v_{x0} + a_x t$

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

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

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

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

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

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

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

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

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

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

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

$\Delta U_g = mg\Delta h$

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

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

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

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

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

$v = r\omega$

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

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

$\omega = \omega_0 + \alpha t$

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

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

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

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

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

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

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

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

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

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

ELECTRICITY AND MAGNETISM

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

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

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

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

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

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

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

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

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

$C_p = \sum_i C_i$

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

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

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

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

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

$I = Nev_d A$

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

$R_s = \sum_i R_i$

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

$P = I\Delta V$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
ε = 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

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

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

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

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

$B_s = \mu_0 n I$

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

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

$\varepsilon = -L\frac{dI}{dt}$

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

ADVANCED PLACEMENT PHYSICS C EQUATIONS

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

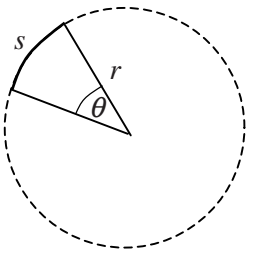
$a^2 + b^2 = c^2$

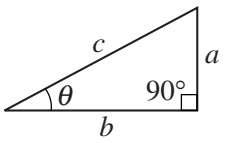
$\sin\theta = \frac{a}{c}$

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

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

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

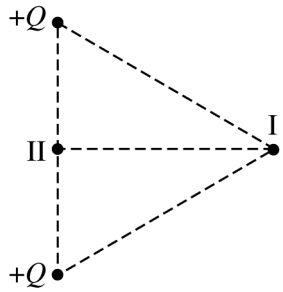
$\vec{A}\bullet\vec{B} = AB\cos\theta$

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

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



In the figure above, two small spheres, each with charge $+Q$, are fixed in place at the corners of an equilateral triangle. Point I is at the third corner, and point II is midway between the charges.

1. A small particle with charge $+q$, where $q << Q$, is moved from point I to point II at constant speed v by an external force. W_{EXT} is the work done by the external force on the moving charge, and W_{ELEC} is the work done by the electrostatic force. Which of the following correctly identifies the signs of these quantities?

	W_{EXT}	W_{ELEC}
(A)	+	+
(B)	+	−
(C)	−	+
(D)	−	−

(E) None of the above, since the work done by both the external force and the electrostatic force is zero.

2. Which of the following best describes the relationship between the electric potentials V_I and V_{II} at points I and II, respectively?

(A) $V_I < V_{II}$
(B) $V_I = V_{II}$
(C) $V_I > V_{II}$
(D) It cannot be determined without knowing the magnitudes of the charges.
(E) It cannot be determined without knowing the distance between points I and II.

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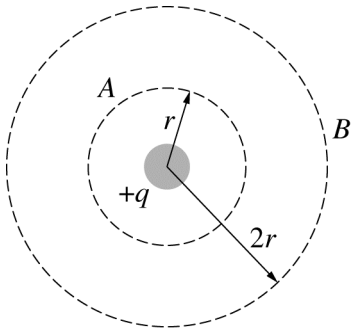
Questions 3-4



A small sphere has a charge $+q$. Spherical Gaussian surfaces A and B are concentric with the sphere, as shown in the figure above. The radii of surfaces A and B are r and $2r$, respectively.

3. The magnitude of the electric flux through A is Φ_A. The magnitude of the electric flux through surface B is Φ_B. The ratio Φ_A/Φ_B is

   (A) 4/1
   (B) 2/1
   (C) 1/1
   (D) 1/2
   (E) 1/4

4. The magnitude of the electric field at surface A is E_A. The magnitude of the electric field at surface B is E_B. The ratio E_A/E_B is

   (A) 4/1
   (B) 2/1
   (C) 1/1
   (D) 1/2
   (E) 1/4

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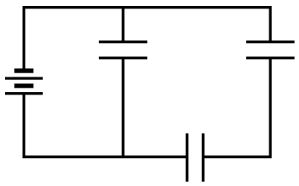
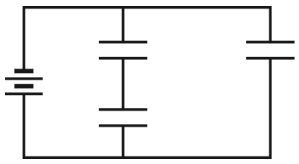
5. Each of the following figures shows three identical capacitors connected to a battery. Which arrangement has the greatest equivalent capacitance?

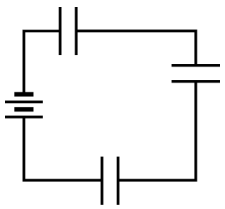
(A)



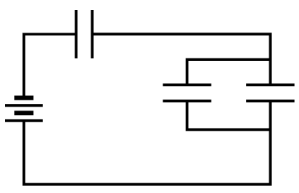
(B)



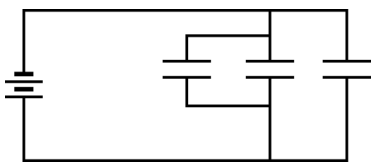
(C)



(D)



(E)



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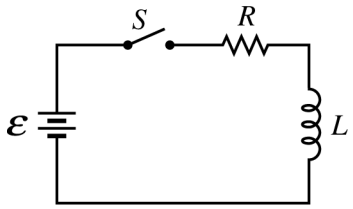
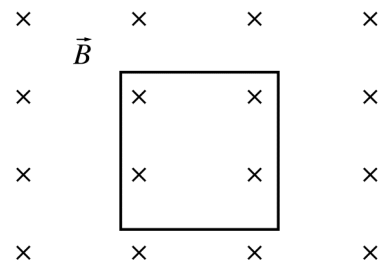
6. A copper wire of length L and diameter D dissipates energy at a rate P_0 when the current in the wire is 10 A. A second copper wire of length L has diameter $2D$. What current in the second wire would dissipate energy at a rate P_0 ?

(A) 2.5 A
(B) 5.0 A
(C) 10 A
(D) 20 A
(E) 40 A



7. Time t is the time it takes the current of an LR circuit with an inductor of inductance L and a resistor of resistance R to reach half of its maximum value. What is the new time if the original inductor is replaced with an inductor of inductance $2L$?

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



8. A loop of wire lies in the plane of the page in a region with a uniform magnetic field $\vec{B}$ directed into the page, as shown in the figure above. In which of the following cases, if any, will an emf be induced in the loop at the moment shown in the figure?

(A) The loop is moving toward the right.
(B) The loop is moving toward the top of the page.
(C) The loop is moving out of the plane of the paper so that the loop's plane remains perpendicular to the magnetic field.
(D) The loop is moving into the plane of the paper so that the loop's plane remains perpendicular to the magnetic field.
(E) An emf cannot be induced in the loop without changing its orientation relative to the magnetic field.

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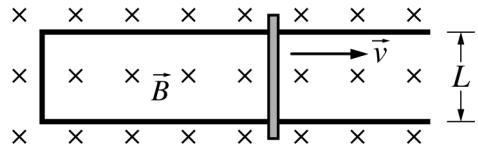

Top View

9. A copper rod of resistance R is in electrical contact with a frictionless U-shaped rail of width L and negligible resistance. The rod is pulled to the right at a constant velocity $\vec{v}$. A magnetic field $\vec{B}$ is directed into the page, as shown in the figure above. Under these conditions, the electric power dissipated in the rod is P. If the velocity of the rod is doubled and the magnetic field strength is reduced by half, the power dissipated in the rod is

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

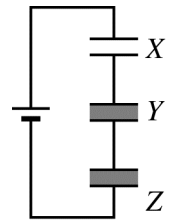

Figure 1

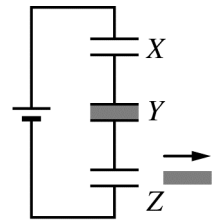

Figure 2

10. Three capacitors are connected in series to an ideal voltage source and charged, as shown in Figure 1 above. The capacitors are identical except that capacitor X has air between its plates, whereas capacitors Y and Z each have a dielectric slab of dielectric constant $\kappa > 1$ between their plates. If the dielectric slab is removed from capacitor Z, as shown in Figure 2, which of the following describes what will happen to the voltage across each capacitor?

	Voltage across Capacitor X	Voltage across Capacitor Y	Voltage across Capacitor Z
(A)	Increases	Increases	Decreases
(B)	Increases	Decreases	Decreases
(C)	Increases	Decreases	Increases
(D)	Decreases	Increases	Decreases
(E)	Decreases	Decreases	Increases

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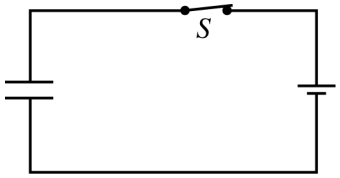
Questions 11-12



A parallel-plate capacitor connected to a battery is fully charged with the switch S closed, as shown in the circuit above. A slab of dielectric constant $\kappa > 1$ is slowly inserted between the plates of the capacitor.

11. If the switch remains closed when the slab is inserted, what changes, if any, occur?

	Potential Difference Across the Plates	Charge on Positive Plate
(A)	Remains the same	Increases
(B)	Remains the same	Decreases
(C)	Increases	Remains the same
(D)	Decreases	Increases
(E)	Decreases	Remains the same

12. If, instead, the switch is open with the capacitor still fully charged when the slab is inserted, what changes, if any, occur?

	Potential Difference Across the Plates	Charge on Positive Plate
(A)	Remains the same	Increases
(B)	Remains the same	Decreases
(C)	Increases	Remains the same
(D)	Decreases	Increases
(E)	Decreases	Remains the same

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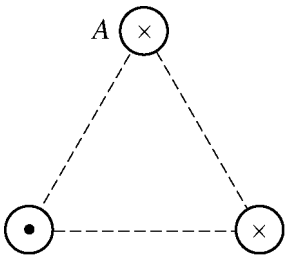


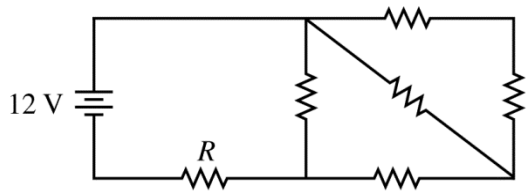
13. Three long wires perpendicular to the page are equidistant from each other, as shown in the cross-sectional view above. Two wires carry current into the page, and the third carries current out of the page. All the currents are equal in magnitude. What is the direction of the net magnetic force on wire *A* due to the other two wires?

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

14. A beam of particles travels at a right angle to a uniform magnetic field. Particles can be separated into different trajectories based on which of the following properties?

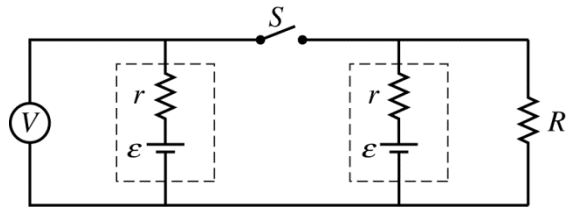
I. The charge of the particle
II. The mass of the particle
III. The velocity of the particle

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



15. Six $2\ \Omega$ resistors are connected to a 12 V battery, as shown in the figure above. What is the current in the resistor labeled *R*?

(A) 2.6A
(B) 3.7A
(C) 4.0A
(D) 4.3A
(E) 6.0A



16. A resistor of resistance *R* is connected in a circuit to two identical batteries. The circuit also contains switch *S* and ideal voltmeter *V*, as shown in the figure above. The batteries both have an emf $\mathcal{E}$ and internal resistance *r*. The reading of the voltmeter is noted with the switch in the open position. Which of the following best represents how the voltmeter reading after the switch is closed compares to the reading before the switch is closed?

(A) The reading of the voltmeter is the same.
(B) The reading of the voltmeter is higher.
(C) The reading of the voltmeter is lower.
(D) Cannot be determined without knowing the internal resistance of the batteries.
(E) Cannot be determined without knowing the emf of the batteries.

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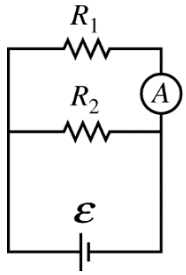
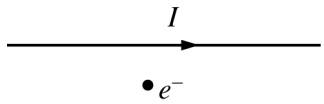


17. In the circuit shown, $R_1 = 6\ \Omega$, $R_2 = 3\ \Omega$, and the emf $\mathcal{E}$ of the battery is 30 V. The reading of the ammeter A is most nearly

(A) 1.6 A
(B) 3.3 A
(C) 5.0 A
(D) 10 A
(E) 15 A

Questions 18-19



An electron is placed near a wire carrying current I, as shown in the figure above, and released from rest. Both the electron and the wire are in the plane of the page.

18. Which of the following is true about the direction of the magnetic field produced by the current at the position of the electron?

(A) It is toward the top of the page.
(B) It is toward the bottom of the page.
(C) It is out of the page.
(D) It is into the page.
(E) It has no direction since there is no magnetic field at that point.

19. Which of the following is true about the direction of the initial magnetic force acting on the electron due to the current in the wire?

(A) It is toward the top of the page.
(B) It is toward the bottom of the page.
(C) It is out of the page.
(D) It is into the page.
(E) It has no direction because the magnitude of the initial magnetic force on the electron is zero.

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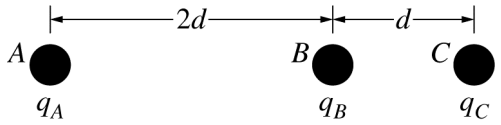
Questions 20-22



Three small spheres, *A*, *B*, and *C*, have charges with magnitudes q_A, q_B, and q_C, respectively. The three spheres are aligned along a straight line, as shown in the figure above. At the instant shown, the net force on sphere *A* is zero.

20. The ratio q_C/q_B is

(A) 9/4
(B) 1/1
(C) 4/9
(D) 1/4
(E) 1/9

21. Which of the following statements must be true of the signs of the charges?

(A) Only charges q_A and q_B have the same sign.
(B) Only charges q_A and q_C have the same sign.
(C) Only charges q_B and q_C have the same sign.
(D) Charges q_B and q_C have different signs.
(E) Charges q_A, q_B, and q_C all have the same sign.

22. Which of the following is true about the sign of charge q_A?

(A) The sign of charge q_A must be the same as that of q_B.
(B) The sign of charge q_A must be the same as that of q_C.
(C) The sign of charge q_A must be the same as that of either q_B or q_C, whichever has the greater magnitude.
(D) The sign of charge q_A must be the same as that of either q_B or q_C, whichever has the lesser magnitude.
(E) It is possible that q_A could be either positive or negative.

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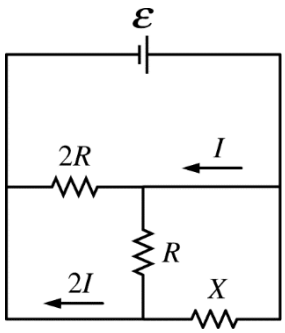
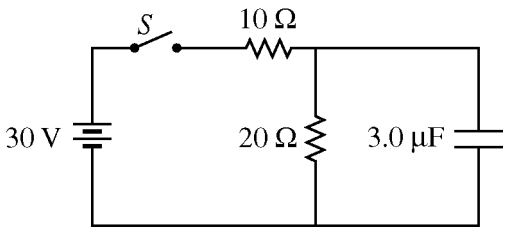


23. Three resistors are connected to an ideal battery, as shown in the figure above. The battery has an emf ε. Two of the resistors have known resistances R and $2R$. The third resistor has unknown resistance X. The current in two of the branches is shown. What is the value of the unknown resistance X ?

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

Questions 24-25



An uncharged 3.0 μF capacitor is placed in a circuit with an ideal battery, two resistors, and an open switch S, as shown in the figure above. The switch is then closed.

24. What is the current in the 10 Ω resistor immediately after the switch is closed?

(A) Zero
(B) 1.0 A
(C) 1.5 A
(D) 3.0 A
(E) 10 A

25. What is the current in the 20 Ω resistor a long time after the switch is closed?

(A) Zero
(B) 1.0 A
(C) 1.5 A
(D) 3.0 A
(E) 10 A

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26. A parallel-plate capacitor connected to an ideal battery has charge $+Q$ on its top plate. The energy stored in the capacitor is U_C. While the capacitor remains connected to the battery, the separation between the two plates is doubled. Which of the following gives the new charge on the top plate and the new energy stored in the capacitor?

	Charge	Potential Energy
(A)	$+2Q$	$2U_C$
(B)	$+2Q$	$U_C/2$
(C)	$+Q$	U_C
(D)	$+Q/2$	$2U_C$
(E)	$+Q/2$	$U_C/2$

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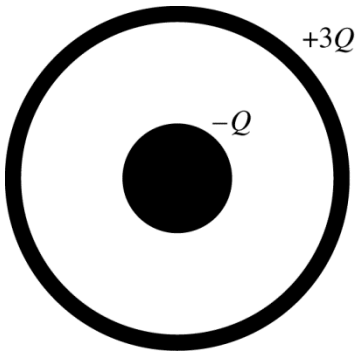
Questions 27-28



A hollow conducting sphere is surrounded by a larger concentric spherical conducting shell, as shown above. The inner sphere has a net charge of $-Q$, and the outer sphere has a net charge of $+3Q$.

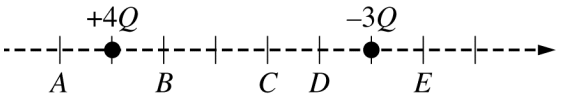
27. What is the net charge on the inner surface of the spherical shell?

(A) $-Q$
(B) 0
(C) $+Q$
(D) $+2Q$
(E) $+3Q$

28. What is the net charge on the outer surface of the spherical shell?

(A) 0
(B) $+Q$
(C) $+2Q$
(D) $+3Q$
(E) $+4Q$

Questions 29-30



Two small spheres are arranged along a line and carry charges of $+4Q$ and $-3Q$, as shown in the figure above. The vertical lines are equally spaced.

29. At which of the labeled points does the electric field point toward the right with the smallest magnitude?

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

30. At which of the labeled points does the electric potential have the largest positive value?

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

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31. Object A and object B are separated by distance d. Object A has charge $+q$, and object B has charge $-2q$. Object A has a force of magnitude F exerted on it by object B. What are the magnitude and direction of the force exerted on object B?

	Magnitude	Direction
(A)	$F/2$	Away from object A
(B)	F	Away from object A
(C)	$2F$	Away from object A
(D)	F	Toward object A
(E)	$2F$	Toward object A

32. A variable voltage source is connected to an inductor of inductance L. The voltage V as a function of time t is given by the equation $V(t) = \beta t^2$, where β is a constant in units of $\mathrm{V/s^2}$. The current in the inductor at time $t = 0$ is zero. Which of the following equations gives the magnitude of the current in the inductor as a function of time?

(A) $I(t) = 0$

(B) $I(t) = \dfrac{2\beta}{L}t$

(C) $I(t) = \dfrac{\beta}{L}t^2$

(D) $I(t) = \dfrac{\beta}{3L}t^3$

(E) $I(t) = \dfrac{\beta}{L}t^2 \sin(\omega t)$

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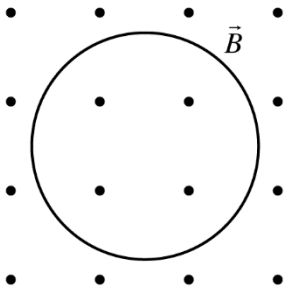


Figure 1

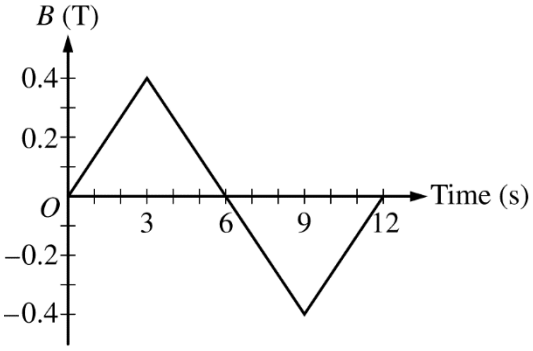
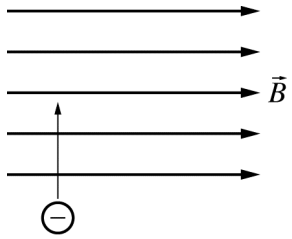


Figure 2

33. A metal wire of resistance 10 Ω is bent into a circular hoop of radius 0.10 meter and placed in a uniform magnetic field, as shown in Figure 1 above. The magnetic field strength B as a function of time is shown in Figure 2, where positive refers to a magnetic field directed out of the page. What are the magnitude and direction of the current induced in the ring at time $t = 6$ s?

	Magnitude	Direction
(A)	3.8 mA	Clockwise
(B)	3.8 mA	Counterclockwise
(C)	0.42 mA	Clockwise
(D)	0.42 mA	Counterclockwise
(E)	0	No direction



34. A negatively charged ion is moving toward the top of the page when it enters a region of space with a uniform magnetic field $\vec{B}$ directed to the right, as shown above. The direction of the force that the magnetic field exerts on the ion is

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

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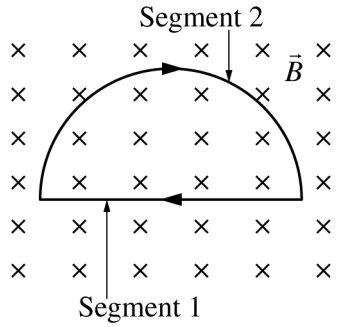

35. A semicircular loop with a clockwise current is placed in a uniform magnetic field that is directed into the page, as shown in the figure above. $\vec{F}_1$ is the net force on segment 1, the straight portion of the loop. $\vec{F}_2$ is the net force on segment 2, the curved portion of the loop. Which of the following correctly indicates the directions and relative magnitudes of the forces $\vec{F}_1$ and $\vec{F}_2$?

	Direction of $\vec{F}_1$	Direction of $\vec{F}_2$	Magnitudes
(A)	Toward the bottom of the page	Toward the top of the page	$\lvert\vec{F}_1\rvert = \lvert\vec{F}_2\rvert$
(B)	Toward the bottom of the page	Toward the top of the page	$\lvert\vec{F}_1\rvert < \lvert\vec{F}_2\rvert$
(C)	Toward the bottom of the page	Toward the top of the page	$\lvert\vec{F}_1\rvert > \lvert\vec{F}_2\rvert$
(D)	Toward the top of the page	Toward the bottom of the page	$\lvert\vec{F}_1\rvert = \lvert\vec{F}_2\rvert$
(E)	Toward the top of the page	Toward the bottom of the page	$\lvert\vec{F}_1\rvert < \lvert\vec{F}_2\rvert$

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 2017 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

2017

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 4NBP4-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, $N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant, $G = 6.67 \times 10^{-11}$ $\left(\text{N}\cdot\text{m}^2\right)/\text{kg}^2$
Universal gas constant, $R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface, $g = 9.8$ 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, $\varepsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\left(\text{N}\cdot\text{m}^2\right)$

Coulomb's law constant, $k = 1/(4\pi\varepsilon_0) = 9.0 \times 10^{9}\ \left(\text{N}\cdot\text{m}^2\right)/\text{C}^2$

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, $1\text{ atm} = 1.0 \times 10^{5}\ \text{N/m}^2 = 1.0 \times 10^{5}$ 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

$v_x = v_{x0} + a_x t$

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

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

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

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

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

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

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

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

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

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

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

$\Delta U_g = mg\Delta h$

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

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

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

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

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

$v = r\omega$

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

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

$\omega = \omega_0 + \alpha t$

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

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

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

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

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

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

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

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

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

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

ELECTRICITY AND MAGNETISM

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

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

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

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

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

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

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

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

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

$C_p = \sum_i C_i$

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

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

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

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

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

$I = Nev_d A$

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

$R_s = \sum_i R_i$

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

$P = I\Delta V$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
ε = 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

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

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

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

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

$B_s = \mu_0 n I$

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

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

$\varepsilon = -L\frac{dI}{dt}$

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

ADVANCED PLACEMENT PHYSICS C EQUATIONS

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

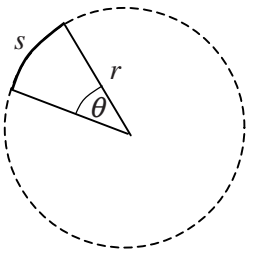
$a^2 + b^2 = c^2$

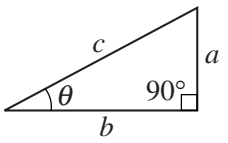
$\sin\theta = \frac{a}{c}$

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

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

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 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.

1. The electric potential in a region of space as a function of position x is given by the equation $V(x) = \alpha x^2 + \beta x - \gamma$, where $\alpha = 2\ \text{V/m}^2$, $\beta = 7\ \text{V/m}$, and $\gamma = 15\ \text{V}$. All nonelectrical forces are negligible.

   (a) An electron starts at rest at $x = 0$ and travels to $x = 20$ m.

   i. Calculate the magnitude of the work done on the electron by the electric field during this process.

   ii. Calculate the speed of the electron at $x = 20$ m.

   (b) Derive an equation for the x-component of the electric field as a function of position x.

   (c)

   i. On the axes below, sketch a graph of the acceleration of the electron a as a function of position x.



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GO ON TO THE NEXT PAGE.

ii. On the axes below, sketch a graph of the kinetic energy of the electron K as a function of position x.



(d) At which of the following locations will an electron that is released from rest move in the negative x direction? Check all that apply.

____ $x = -2$ m ____ $x = +1$ m ____ $x = +3$ m

Justify your answer.

(e) A charged object, generating its own electric field given by $E(x) = 7\ \text{V/m}$, is introduced in the region. What is the potential difference from $x = 0$ m to $x = 20$ m caused by the combination of the original electrical potential and the electric field of the charged object?

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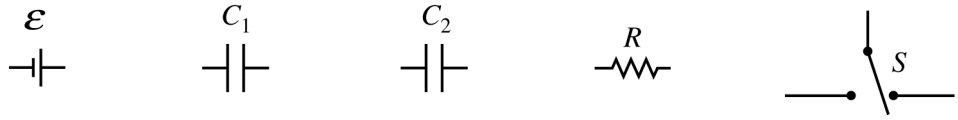
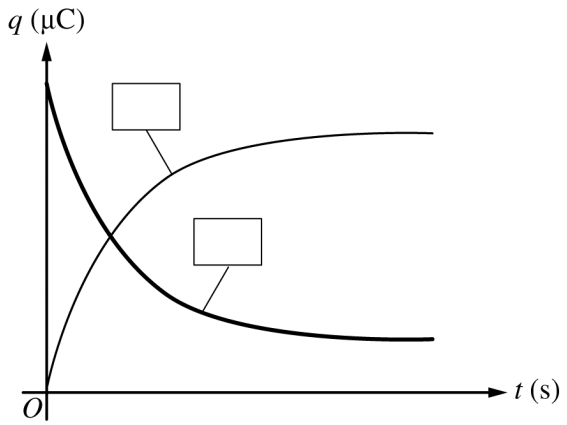
2. A student is to design a circuit using a battery $\mathcal{E}$ with negligible internal resistance, two uncharged capacitors C_1 and C_2, a resistor *R*, and a switch *S*. The circuit should be set up so that when the switch is in one position, the battery will only charge capacitor C_1, and when in the second position, capacitor C_1 will discharge through capacitor C_2 and resistor *R*.

(a) Using the components shown below, draw a circuit diagram that represents a single circuit that will satisfy the criteria outlined above.



The switch *S* is initially in position to fully charge capacitor C_1. At time $t = 0$, the switch is moved to the second position. The charge as a function of time for both capacitors after the switch is moved is plotted on the graph below.

(b) Label each box to indicate which graph corresponds to C_1 and C_2.



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The components of the circuit have the following values: $R = 1000\ \Omega$, $C_1 = 2.0\ \mu\text{F}$, $C_2 = 6.0\ \mu\text{F}$, $\varepsilon = 12\ \text{V}$.

(c) Calculate the following for a long time after the switch has been moved to the second position.

i. The charges q_1 and q_2 stored on capacitors C_1 and C_2, respectively

ii. The potential differences V_1 and V_2 across the capacitors C_1 and C_2, respectively

(d) Calculate the total energy dissipated in resistor *R* during the time capacitor C_1 discharges.

(e)

i. Write, but do NOT solve, a differential equation that could be used to determine the time constant associated with the discharge of C_1.

ii. Calculate the time constant associated with the discharge of C_1.

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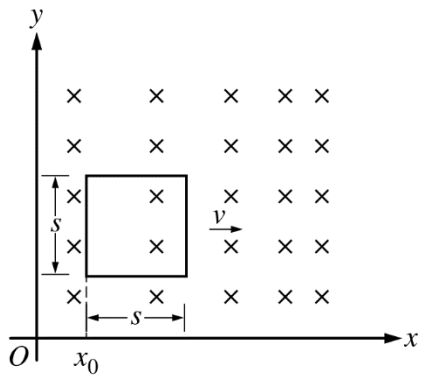

3. A square loop of conducting wire with resistance R and with sides of length s is located in the xy-plane. The loop is being pushed at constant speed v by an external force of magnitude F_{ext} in the $+x$-direction through a region with a magnetic field that is directed perpendicular to the xy-plane into the page, as shown in the figure above. The magnitude of the magnetic field as a function of position x is given by the equation $B(x) = cx + B_0$, where x is in meters, c is a positive constant in $\mathrm{T/m}$, and B_0 is a positive constant in teslas. The effects of gravity are negligible.

   (a) Derive an expression for the magnetic flux through the loop when the left side of the loop is at position $x = x_0$. Express your answer in terms of s, c, B_0, x_0, and physical constants, as appropriate.

   (b) Derive an expression for the magnitude of the induced current in the loop, if any. Express your answer in terms of R, s, v, c, B_0, x, and physical constants, as appropriate.

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GO ON TO THE NEXT PAGE.

(c) Is the induced current in the loop clockwise, counterclockwise, or zero?

____ Clockwise ____ Counterclockwise ____ Zero

Justify your answer.

(d) When the left side of the loop is at position $x = x_0$ and moving with constant speed v, what is the direction of the net magnetic force, if any, on the loop?

____ Toward the top of the page ____ Out of the page ____ Left

____ Toward the bottom of the page ____ Into the page ____ Right

____ Undefined, because the net magnetic force on the loop is zero.

Justify your answer.

(e) Derive an expression for the magnitude of the external force F_{ext} exerted on the loop to keep it moving at a constant speed when the loop is at position $x = x_0$. Express your answer in terms of R, s, v, c, B_0, x_0, and physical constants, as appropriate.

(f) Rank, with 1 being the largest, the magnitude of the magnetic force on the four sides of the loop. If two sides have the same magnetic force, give them the same numerical ranking.

____ Left _____ Right _____ Top ____ Bottom

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GO ON TO THE NEXT PAGE.

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: B

Question 2: A

Question 3: C

Question 4: A

Question 5: E

Question 6: D

Question 7: B

Question 8: E

Question 9: C

Question 10: E

Question 11: A

Question 12: E

Question 13: E

Question 14: E

Question 15: B

Question 16: C

Question 17: C

Question 18: D

Question 19: E

Question 20: A

Question 21: D

Question 22: E

Question 23: C

Question 24: D

Question 25: B

Question 26: E

Question 27: C

Question 28: C

Question 29: C

Question 30: A

Question 31: D

Question 32: D

Question 33: D

Question 34: D

Question 35: A

Free-Response Scoring Guidelines

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

AP® PHYSICS C: ELECTRICITY AND MAGNETISM
2017 SCORING GUIDELINES

Question 1

15 points total **Distribution of points**

(a)

i) 2 points

For using the equation relating the potential difference to the magnitude of the work done on the electron 1 point

$$W = |q||\Delta V| = \left(1.6 \times 10^{-19}\ \text{C}\right)\left[\left((2)(20\ \text{m})^2 + (7)(20\ \text{m}) - (15)\right) - (0 + 0 - 15)\right]$$

For a correct answer with units 1 point

$$W = 1.50 \times 10^{-16}\ \text{J} = 940\ \text{eV}$$

ii) 2 points

For using the equation relating the magnitude of the work done on the electron to the speed of the electron 1 point

$$W = \Delta K = \frac{1}{2}m\left(v_2^2 - v_1^2\right) = \frac{1}{2}mv^2$$

For correct substitutions 1 point

$$v = \sqrt{\frac{2W}{m}} = \sqrt{\frac{(2)\left(1.50 \times 10^{-16}\ \text{J}\right)}{\left(9.11 \times 10^{-31}\ \text{kg}\right)}}$$

$$v = 1.82 \times 10^{7}\ \text{m/s}$$

(b) 2 points

For taking the derivative of the electric potential to calculate the electric field 1 point

$$E_x = -\frac{dV}{dx} = -\frac{d}{dx}\left(2x^2 + 7x - 15\right)$$

For a correct answer 1 point

$$E_x = -4x - 7$$

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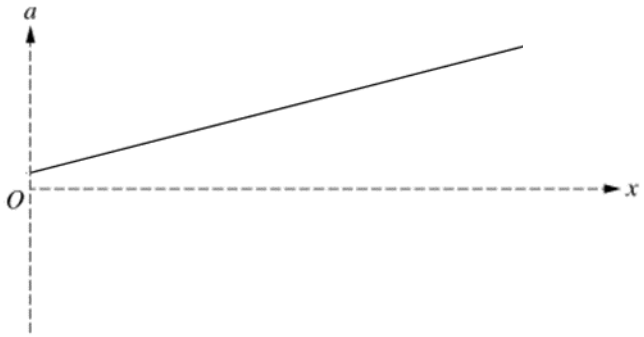
Question 1 (continued)

Distribution of points

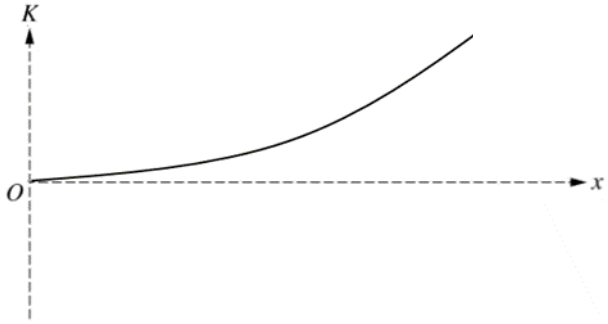
(c)

i) 2 points



For a straight line for $x > 0$ with non-zero slope — 1 point
For a line with positive slope and positive y intercept — 1 point

ii) 2 points



For a graph starting at the origin and extending into the first quadrant — 1 point
For a concave up curve with $K \geq 0$ — 1 point

(d) 2 points

For selecting only "$x = -2$ m" — 1 point
For a correct justification — 1 point
Example: Electrons accelerate opposite the direction of the electric field. Therefore the electron will accelerate in the negative direction only if the electric field is directed in the positive direction. The electric field is positive only for $x < -1.75$ m.
Note: If incorrect selection is made, justification cannot earn credit.

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Question 1 (continued)

Distribution of points

(e) 3 points

Starting with the integration of the net electric field to determine the potential difference

$V_{20} - V_0 = -\int E \bullet dx$

For recognizing that $E = E_1 + E_2$ 1 point

$V_{20} - V_0 = -\int E_{net} \bullet dx = -\int (E_1 + E_2) \bullet dx$

For the substitution of the correct expressions for the electric fields 1 point

$\Delta V = -\int (E_1 + E_2)\, dx = -\int [(-4x - 7) + 7]\, dx = -\int -4x dx = \int_{x=0}^{x=20} 4x dx$

For a substitution with the correct limits and signs 1 point

$\Delta V = \left[2x^2\right]_{x=0}^{x=20} = (2)(20)^2 - (2)(0)^2$

$\Delta V = 800 \text{ V}$

Alternate solution *Alternate points*

For correctly recognizing that the potential difference is equal to the sum of potential differences due to each electric field. *1 point*

$\Delta V = \Delta V_1 + \Delta V_2$

For determining the potential difference of the original field from part (a) *1 point*

$\Delta V_1 = V(20) - V(0) = 925 - (-15) = 940 \text{ V}$

For correctly determining the potential difference due to the field generated by the charged object *1 point*

$\Delta V_2 = -\int_0^{20} E\, dx = -E\Delta x = -\left(7 \frac{\text{V}}{\text{m}}\right)(20 \text{ m}) = -140 \text{ V}$

$\Delta V = 940 + (-140) = 800 \text{ V}$

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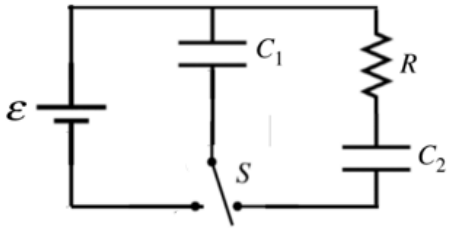
2017 SCORING GUIDELINES

Question 2

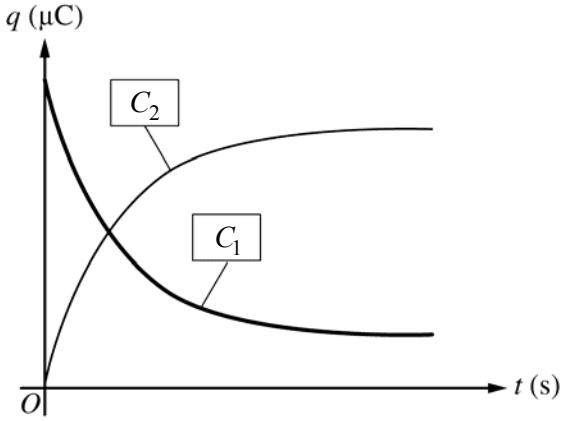
15 points total **Distribution of points**

(a) 4 points



For drawing a circuit with the battery on a branch by itself — 1 point
For having the resistor in series with C_2 — 1 point
For having the switch positioned so that only C_1 can be charged — 1 point
For having the switch positioned so that C_1 can be discharged to C_2 — 1 point

(b) 1 point



For correctly identifying the two curves — 1 point

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Question 2 (continued)

Distribution of points

(c)

i) 3 points

For indicating that the potential difference across the two capacitors is the same — 1 point

$V_1 = V_2$

$\frac{q_1}{C_1} = \frac{q_2}{C_2}$

For correctly relating the final charges on the two capacitors to the original charge on capacitor C_1 — 1 point

$Q_{tot} = q_1 + q_2$

For correctly substituting one of the above equations into the other (note: either equation can be substituted into the other) — 1 point

$\frac{q_1}{C_1} = \frac{q_2}{C_2} \therefore \frac{q_1}{(2.0\ \mu\text{F})} = \frac{q_2}{(6.0\ \mu\text{F})} \therefore q_2 = 3q_1$

$Q_{tot} = q_1 + q_2 \therefore C_1\mathcal{E} = q_1 + 3q_1 = 4q_1$

$(2.0\ \mu\text{F})(12\ \text{V}) = 4q_1 \therefore q_1 = 6.0\ \mu\text{C}$

$q_2 = Q_{tot} - q_1 = 24\ \mu\text{C} - 6.0\ \mu\text{C} = 18\ \mu\text{C}$

$q_1 = 6.0\ \mu\text{C}$

$q_2 = 18\ \mu\text{C}$

ii) 1 points

For correct numerical substitution from part ci into correct equation — 1 point

$V_1 = \frac{q_1}{C_1} = \frac{(6.0\ \mu\text{C})}{(2.0\ \mu\text{F})} = 3.0\ \text{V}$

$V_2 = V_1 = 3.0\ \text{V}$

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Question 2 (continued)

Distribution of points

(d) 3 points

For indicating that the energy dissipated in the resistor is the difference in the initial and final energy stored in the capacitors — 1 point

$E = \Delta U = U_i - U_f$

For indicating the final energy stored is the sum of the energy across the two capacitors — 1 point

$E = U_{1i} - \left(U_{1f} + U_{2f}\right) = \left(\frac{1}{2}C_1\mathcal{E}^2\right) - \left(\frac{q_{1f}^2}{2C_1} + \frac{q_{2f}^2}{2C_2}\right)$

For correctly substituting numerically into the equation above — 1 point

$E = \left(\frac{1}{2}C_1\mathcal{E}^2\right) - \left(\frac{q_{1f}^2}{2C_1} + \frac{q_{2f}^2}{2C_2}\right) = \left(\frac{1}{2}\right)(2.0\ \mu\text{F})(12\ \text{V})^2 - \left(\frac{(6.0\ \mu\text{C})^2}{(2)(2.0\ \mu\text{F})} + \frac{(18\ \mu\text{C})^2}{(2)(6.0\ \mu\text{F})}\right)$

$E = 108\ \mu\text{J}$

(e)

i) 2 point

For an application of Kirchhoff's loop rule to the circuit with the switch in the second position — 1 point

$V_{C1} - V_{C2} - V_R = 0$

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

For a correct differential equation that could be used to calculate the time constant associated with the discharging of C_1 — 1 point

$\frac{Q - q}{C_1} - \frac{q}{C_2} - R\frac{dq}{dt} = 0$

ii) 1 points

For indicating that the time constant, RC, can be calculated using capacitors in series — 1 point

$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{6} + \frac{1}{2} = \frac{4}{6}$

$C_{eq} = 1.5\ \mu\text{F}$

$\tau = RC = (1000\ \Omega)(1.5\ \mu\text{F})$

$\tau = 1.5\ \text{ms}$

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Question 3

15 points total **Distribution of points**

(a) 3 points

For substituting the expression for the magnetic field into the integration to calculate the magnetic flux 1 point

$$\Phi = \int B \bullet dA = \int (cx + B_0)\, s\, dx$$

For integrating the expression above using proper limits or constants of integration 1 point

$$\Phi = s\left[\frac{cx^2}{2} + B_0 x\right]_{x=x_0}^{x=x_0+s} = s\left[\left(\frac{c(x_0+s)^2}{2} + B_0(x_0+s)\right) - \left(\frac{c(x_0)^2}{2} + B_0(x_0)\right)\right]$$

$$\Phi = s\left(\frac{cx_0^2 + 2csx_0 + cs^2}{2} + B_0 x_0 + B_0 s - \left(\frac{cx_0^2}{2} + B_0 x_0\right)\right)$$

For a correct answer 1 point

$$\Phi = s^2\left(cx_0 + \frac{1}{2}cs + B_0\right)$$

(b) 3 points

For using the derivative of the expression from part (a) to calculate the emf 1 point

$$\mathcal{E} = \left|-\frac{d\Phi}{dt}\right| = \frac{d}{dt}\left[s^2\left(cx + \frac{1}{2}cs + B_0\right)\right]$$

For applying the chain rule and substituting v for dx/dt 1 point

$$\mathcal{E} = \frac{d\Phi}{dx}\frac{dx}{dt} = \frac{d}{dx}\left[s^2\left(cx + \frac{1}{2}cs + B_0\right)\right]v = vs^2\frac{d}{dx}\left(cx + \frac{1}{2}cs + B_0\right)$$

$$\mathcal{E} = vs^2 c$$

For dividing by the resistance to calculate the current 1 point

$$I = \frac{\mathcal{E}}{R} = \frac{\left(vs^2 c\right)}{R} = \frac{vs^2 c}{R}$$

(c) 2 points

Selecting "Counterclockwise"

For indicating that the magnetic flux inside the loop is increasing with time 1 point

For correctly using Lenz's law to relate the change in flux to the direction of the induced current 1 point

Example: As the loop moves toward the right, the magnetic field is increasing so the magnetic flux inside the loop is increasing. According to Lenz's law, the induced current must create a magnetic field that is out of the page to oppose this increasing flux. Therefore, the current in the loop must be counterclockwise.

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Question 3 (continued)

Distribution of points

(d) 3 points

For correctly selecting "Left" 1 point
For indicating that the magnetic forces on the top and bottom parts of the loop are of equal magnitude 1 point
For indicating that the magnetic force on the right side of the loop is greater than the force on the left side of the loop 1 point
Example: The magnitude of the magnetic field is the same for the top and bottom of the loop so the forces on the top and bottom of the loop are equal in magnitude and opposite in direction and thus cancel out. The magnitude of the magnetic field is greater at the right side of the loop than at the left side of the loop thus the net force is in the direction of the force on the right side of the loop and this would be toward the left.

(e) 3 points

For indicating that the magnetic force on the loop is the difference in the force on the left and right sides of the loop 1 point
$F_{ext} = F_R - F_L = B_R IL - B_L IL$
For correctly substituting for the magnetic fields into the above equation 1 point
$F_{ext} = IL(B_R - B_L) = Is[(c(x+s)+B_0) - (cx + B_0)]$
For correctly substituting current from part (b) 1 point
$F_{ext} = \left(\frac{vs^2 c}{R}\right) s(cs) = \frac{vs^4 c^2}{R}$

(f) 1 point

For correctly indicating the correct rankings 1 point
__3__ Left __1__ Right __2__ Top __2__ Bottom

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Scoring Worksheet

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

2017 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
49-90	5
36-48	4
30-35	3
21-29	2
0-20	1

Question Descriptors and Performance Data

The following contains tables showing the content assessed,
the correct answer, and how AP students performed on each question.

2017 AP Physics C: Electricity and Magnetism
Question Descriptors and Performance Data

Multiple-Choice Questions

Questions	Topic	Key	% Correct
1	Electrostatics	B	60
2	Electrostatics	A	70
3	Electrostatics	C	53
4	Electrostatics	A	58
5	Electric circuits	E	85
6	Electric circuits	D	43
7	Electromagnetism	B	61
8	Electromagnetism	E	65
9	Electromagnetism	C	71
10	Conductors/capacitors/dielectrics	E	40
11	Conductors/capacitors/dielectrics	A	48
12	Conductors/capacitors/dielectrics	E	51
13	Magnetostatics	E	38
14	Magnetostatics	E	39
15	Electric circuits	B	39
16	Electric circuits	C	26
17	Electric circuits	C	62
18	Magnetostatics	D	77
19	Magnetostatics	E	41
20	Electrostatics	A	70
21	Electrostatics	D	78
22	Electrostatics	E	68
23	Electric circuits	C	40
24	Electric circuits	D	63
25	Electric circuits	B	61
26	Conductors/capacitors/dielectrics	E	54
27	Conductors/capacitors/dielectrics	C	54
28	Conductors/capacitors/dielectrics	C	66
29	Electrostatics	C	42
30	Electrostatics	A	49
31	Electrostatics	D	67
32	Electromagnetism	D	57
33	Electromagnetism	D	34
34	Magnetostatics	D	72
35	Magnetostatics	A	27

2017 AP Physics C: Electricity and Magnetism
Question Descriptors and Performance Data

Free-Response Questions

Question	Topic	Mean Score
1	Electrostatics	6.68
2	Electric circuits	5.68
3	Electromagnetism	3.95

AP Physics C: Electricity and Magnetism

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