From the 2018 Administration

AP CollegeBoard

AP Physics C: Electricity and Magnetism

Practice Exam

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Note: This publication shows the page numbers that appeared in the ***2017–18 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 ***2017–18 AP Exam Instructions*** book.

AP Physics C: Electricity and Magnetism Exam

Regularly Scheduled Exam Date: Monday afternoon, May 14, 2018

Late-Testing Exam Date: Wednesday afternoon, May 23, 2018

Section I	**Total Time:** 45 minutes Calculator Allowed **Number of Questions:** 35 *(The number of questions may vary slightly depending on the form of the exam.)* **Percent of Total Score:** 50% **Writing Instrument:** Pencil required
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

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.

What Proctors Need to Bring to This Exam

- ☐ Exam packets
- ☐ Answer sheets
- ☐ AP Student Packs
- ☐ *2017-18 AP Coordinator's Manual*
- ☐ This book—*2017-18 AP Exam Instructions*
- ☐ AP Exam Seating Chart template
- ☐ School Code and Homeschool/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 during the test administration, including breaks"

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 52 of the *2017-18 AP Coordinator's Manual*. See pages 49–52 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, they must hand copy, date, and sign the release statement on page 51 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 303–304 for a seating chart template and instructions. See the *2017-18 AP Coordinator's Manual* for exam seating requirements (pages 55–58).

If you are giving the regularly scheduled exam, say:
It is Monday afternoon, May 14, 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 Wednesday afternoon, May 23, and you will be taking the AP Physics C: Electricity and Magnetism Exam.

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:

In a moment, you will open the exam packet. By opening this packet, you agree to all of the AP Program's policies and procedures outlined in the *2017-18 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. 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.

Listen carefully to all my instructions. I will give you time to complete each step. Please look up after completing each step. Raise your hand if you have any questions.

Give students enough time to complete each step. Don't move on until all students are ready.

Read the statements on the front cover of the Section I booklet. . . .

Sign your name and write today's date. . . .

Now print your full legal name where indicated. . . .

Turn to the back cover of your exam booklet and read it completely. . . .

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 _____ . **Note Stop Time** _____ .

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. 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 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, faceup. 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, faceup. I will now collect your Section I booklet. . . .

Collect a Section I booklet from each student. Check that each student has signed the front cover of the sealed Section I booklet.

SECTION II: Free Response

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 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, 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? . . .

If this is your last AP Exam, you may keep your Student Pack. Place it under your chair for now. Otherwise I will collect all Student Packs. . . .

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, 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 _____. Note Stop Time _____.

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, faceup. . . .

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 after the exam (see page 67 of the *2017-18 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 their 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.

After-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.

NOTE: If you administered exams to students with accommodations, review the *2017-18 AP Coordinator's Manual* and the *2017-18 AP SSD Guidelines* for information about completing the NAR form, and returning these exams.

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:

- Complete an Incident Report for any students who used extra paper for the free-response section. (Incident Report forms are provided in the coordinator packets sent with the exam shipments.) **These forms must be completed with a No. 2 pencil.** It is best to complete a single Incident Report for multiple students per exam subject, per administration (regular or late testing), as long as all required information is provided. Include all exam booklets with extra sheets of paper in an Incident Report return envelope (see page 67 of the *2017-18 AP Coordinator's Manual* for complete details).
- Return all exam materials to secure storage until they are shipped back to the AP Program. (See page 26 of the *2017-18 AP Coordinator's Manual* for more information about secure storage.) 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 *2017-18 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.)

CollegeBoard AP

Answer Sheet 2018

AP Number Label
(from Student Pack)

AP FPO X123456789 X

AP Exam Label
(from Section I Booklet)

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

I am aware of and agree to follow the policies and procedures in the *2017-18 Bulletin for AP Students and Parents* to maintain the security of the exam and the validity of my AP score. I understand and accept that my exam score may be canceled if I do not follow these policies and procedures, if I disregard any exam day instructions, or if my exam is administered improperly. I certify that I am the person whose information appears on this answer sheet.

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:

801356

SCHOOL USE ONLY

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

Fee Reduction Granted: 1 Option 1 2 Option 2

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Q4546/1-4

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

FOR OFFICIAL 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
- 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

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 *2017-18 Bulletin for AP Students and Parents*.

Section I: Multiple-Choice Questions

This is the multiple-choice section of the 2018 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

2018

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 4OBP4-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 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 u $= 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\varepsilon_0 = 8.85 \times 10^{-12}$ $\text{C}^2/\left(\text{N}\cdot\text{m}^2\right)$
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 atm $= 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

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

PREFIXES		
Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following 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
$\mathcal{E}$ = 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

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

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

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

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

$B_s = \mu_0 n I$

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

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

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

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

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

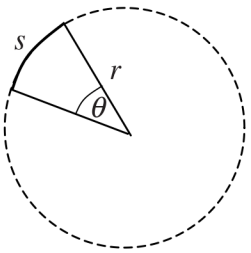
$a^2 + b^2 = c^2$

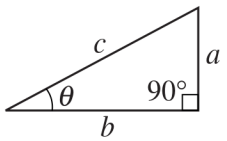
$\sin\theta = \frac{a}{c}$

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

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

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

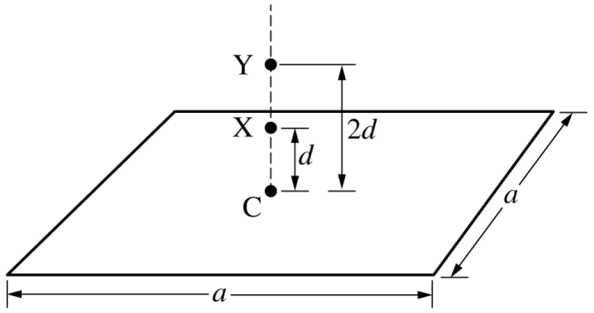
SECTION I

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



Note: Figure not drawn to scale.

The figure above shows a thin, square, nonconducting sheet of positive charge uniformly distributed over its area. The length of each side of the sheet is a. Point C is at the center of the sheet. Point X is a distance d above the center of the sheet, and point Y is a distance $2d$ above the center of the sheet. Assume $a >> d$. The effect of gravity is negligible.

1. If the magnitude of the electric field at point X is E, what is the magnitude of the electric field at point Y?

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

2. A positive point charge $+q$ is released from rest at point X. If the magnitude of the electric field at point X is E, what is the kinetic energy of the charge at point Y?

   (A) qEd
   (B) $\sqrt{2}qEd$
   (C) $2qEd$
   (D) $2\sqrt{2}qEd$
   (E) $4qEd$

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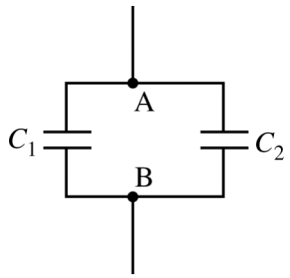

3. Capacitors C_1 and C_2 are connected as shown in the circuit above. The capacitance of C_1 is C, and the capacitance of C_2 is $C/3$. The equivalent capacitance between points A and B is C_{EQ}. A dielectric is inserted into capacitor C_2, and the equivalent capacitance between points A and B is now $2C_{EQ}$. What is the value of the dielectric constant for this dielectric?

(A) 2
(B) 3
(C) 4
(D) 5
(E) The value cannot be determined without knowing the value of C.

4. Which of the following could be true for a Gaussian surface through which the net flux is zero?

I. There are no charges inside the surface.
II. The net charge enclosed by the surface is zero.
III. The electric field is zero everywhere on the surface.

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

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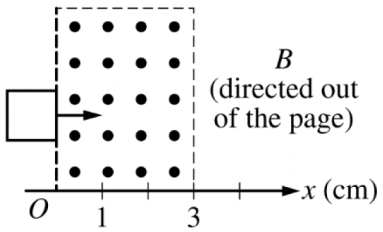
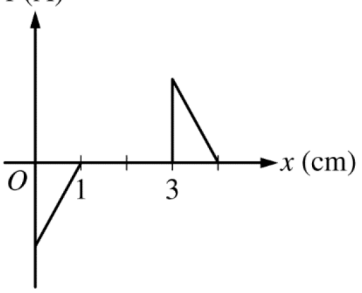
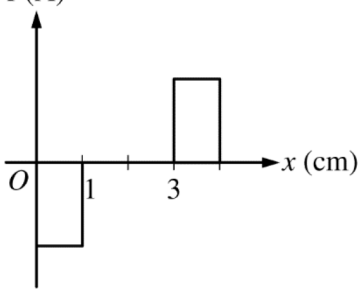
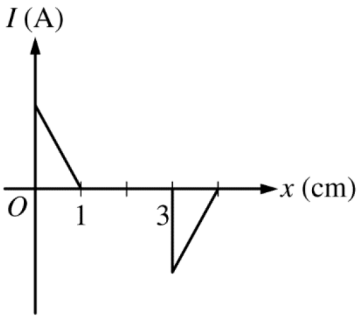
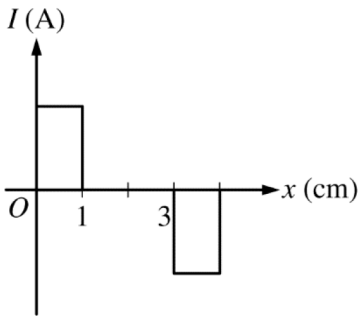


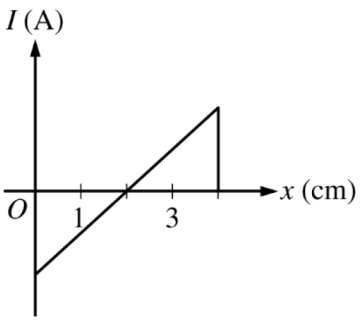
5. A square coil with sides of length 1.0 cm is moved through a region of uniform magnetic field at a constant speed, as shown in the figure above. Which of the following graphs best shows the current I in the coil as a function of the position x of the right edge as the coil moves through the magnetic field, where counterclockwise current is positive?

(A)


(B)


(C)


(D)


(E)


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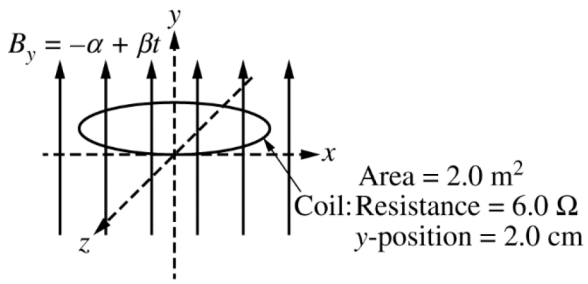
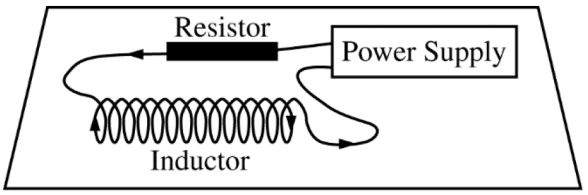


6. The y-component of the magnetic field B is given as a function of time t by the equation $B_y = -\alpha + \beta t$, where $\alpha = 4.0$ T and $\beta = 3.0$ T/s. A coil of wire with an area of $2.0\ \text{m}^2$ and a resistance of $6.0\ \Omega$ is placed in this field, parallel to the xz-plane at y= 2.0 cm. The current in the coil at time $t = 1.2$ s is most nearly

(A) 0
(B) 0.60 A
(C) 1.0 A
(D) 3.6 A
(E) 6.0 A



7. An inductor with inductance $L = 0.30$ H is connected in series with a resistor and both are connected to a power supply, as shown above. The power supply generates a current I that is given as a function of time t by the equation $I = I_0(1 - t/k)$, where $I_0 = 4.0$ A and $k = 2.0$ s. What is the magnitude of the potential difference across the inductor induced by the changing current?

(A) 0.15 V
(B) 0.30 V
(C) 0.60 V
(D) 1.2 V
(E) 2.4 V

8. A parallel plate capacitor with air between the plates is charged and then disconnected from the source of emf. If the space between the plates is now filled with a dielectric, what happens to the capacitance of the capacitor and the magnitude of the electric field between the plates?

	Capacitance	Magnitude of the Electric Field
(A)	Increases	Increases
(B)	Increases	Remains constant
(C)	Increases	Decreases
(D)	Decreases	Increases
(E)	Decreases	Decreases

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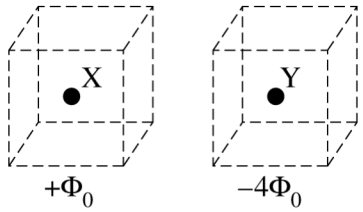
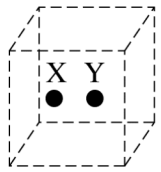
Questions 9-11



The figure above shows two charged spherical conductors, X and Y, which are equal in size. When each conductor is isolated and surrounded by a closed cubical surface, the total electric flux through the surfaces is $+\Phi_0$ for conductor X and $-4\Phi_0$ for conductor Y.



9. Conductor Y is brought into contact with conductor X and then separated. If the separation is small so that both conductors are inside the same closed cubical surface, as shown above, what is the total electric flux through the surface?

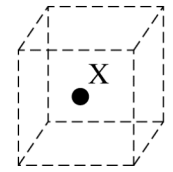
   (A) $-3\Phi_0$

   (B) $-\frac{5}{2}\Phi_0$

   (C) $-\frac{3}{2}\Phi_0$

   (D) $\frac{5}{2}\Phi_0$

   (E) It cannot be determined without knowing the distance separating the two conductors and the individual charges on each.



10. After being brought into contact with conductor X, conductor Y is moved a very large distance away from conductor X. What is the total electric flux through a closed cubical surface surrounding conductor X, as shown above?

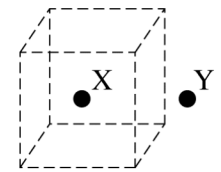
    (A) $-3\Phi_0$

    (B) $-\frac{3}{2}\Phi_0$

    (C) $\frac{1}{2}\Phi_0$

    (D) Φ_0

    (E) $\frac{3}{2}\Phi_0$



11. Conductor Y is then moved closer to conductor X until it is just outside a closed cubical surface containing conductor X, as shown in the figure above. How would the total electric flux through the cubical surface change as conductor Y is moving?

    (A) It would increase.
    (B) It would decrease.
    (C) It would change sign.
    (D) It would remain constant, with the flux through each side of the surface also remaining constant.
    (E) It would remain constant, but the flux through each side of the cubical surface would change.

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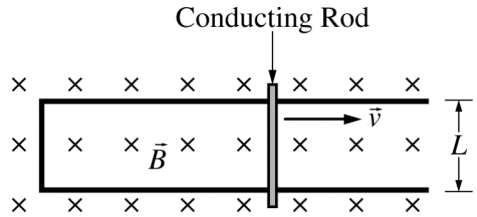

Top View

12. A conducting 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, the power dissipated in the rod is

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

13. Which of the following will increase the magnetic field on the axis of a long solenoid?

I. Increasing the current in the solenoid
II. Increasing the cross-sectional area of the solenoid
III. Inserting an iron core into the solenoid

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

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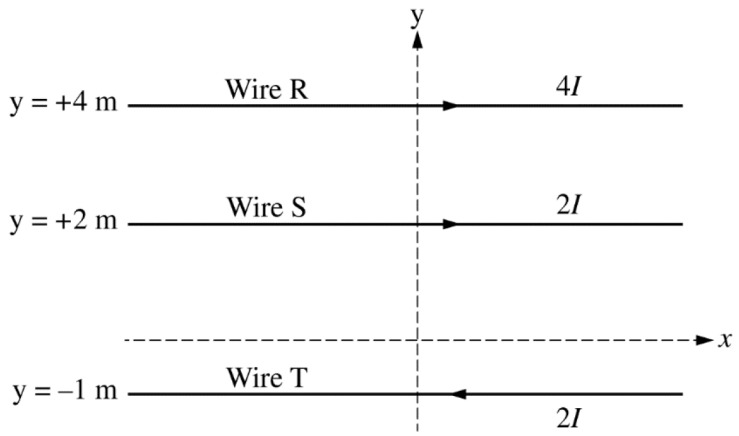

14. Three long wires, R, S, and T, are in the positions and carrying the currents indicated in the figure above. All currents are in the plane of the page and in the direction indicated. What are the magnitude and direction of the magnetic field at the origin?

	Magnitude	Direction
(A)	$\frac{\mu_0 I}{\pi}$	Into the page
(B)	$\frac{\mu_0 I}{\pi}$	Out of the page
(C)	$\frac{2\mu_0 I}{\pi}$	Into the page
(D)	$\frac{2\mu_0 I}{\pi}$	Out of the page
(E)	$\frac{4\mu_0 I}{\pi}$	Out of the page

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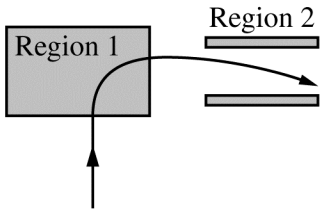
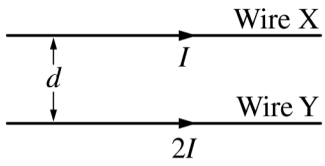


15. A positively charged particle travels along the path shown in the figure above through region 1 and between two parallel plates in region 2. A magnetic field exists in region 1, and one of the plates in region 2 is at a higher potential than the other. What is the direction of the magnetic field in region 1, and which plate is at a higher potential in region 2 ?

	Region 1	Plate at Higher Potential
(A)	Out of the page	Top plate
(B)	Out of the page	Bottom plate
(C)	Into the page	Top plate
(D)	Into the page	Bottom plate
(E)	To the right	Bottom plate



16. Two long, straight parallel wires X and Y are separated by a distance d and carry currents I and $2I$, as shown in the figure above. The force on wire X has magnitude F. If the current in each wire is both doubled and reversed in direction, which of the following is true of the magnitude and direction of the new force on wire X?

	Magnitude	Direction
(A)	F	Unchanged
(B)	$2F$	Reversed
(C)	$2F$	Unchanged
(D)	$4F$	Reversed
(E)	$4F$	Unchanged

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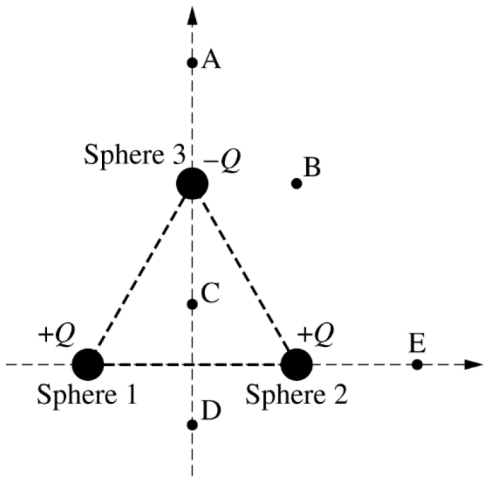
Questions 17-18



Three identical spheres are equally spaced from one another. Spheres 1 and 2 have charge $+Q$, and sphere 3 has a charge of $-Q$, as shown in the figure above. Five different positions are labeled A, B, C, D, and E. Positions A, B, and C are all the same distance from sphere 3. Positions C, D, and E are all the same distance from sphere 2. All spheres and points lie in the same plane.

17. The electric potential is highest at position

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

18. At which of the five positions are the horizontal and vertical components of the electric field directed toward the left and the top of the page, respectively?

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

19. The magnetic field at a perpendicular distance r from a long, straight current-carrying wire is directly proportional to

(A) r
(B) r^2
(C) $1/r$
(D) $1/r^2$
(E) $\ln(r)$

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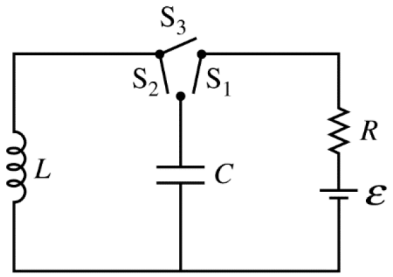
Questions 20-21



A circuit is constructed using a battery of emf $\mathcal{E}$, a resistor of resistance R, a capacitor of capacitance C, an inductor of inductance L, and three switches, as shown in the figure above. The three switches are labeled S_1, S_2, and S_3, and they can be operated independently.

20. All switches are open, and there is no stored energy in the capacitor or the inductor. Switch S_3 is closed. What is the current in the inductor after steady state has been reached?

(A) $\frac{\mathcal{E}}{LR}$

(B) $\frac{\mathcal{E}R}{L}$

(C) $\frac{\mathcal{E}L}{R}$

(D) $\frac{\mathcal{E}}{R}$

(E) Zero

21. All switches are open, and there is no stored energy in the capacitor or the inductor. Switch S_1 is closed. After the capacitor is fully charged, switch S_1 is opened and switch S_2 is closed. Which of the following expressions represents the maximum current in the LC circuit?

(A) $\frac{\mathcal{E}}{R}$

(B) $\mathcal{E}\sqrt{\frac{C}{L}}$

(C) $\mathcal{E}\sqrt{\frac{L}{C}}$

(D) $\frac{\mathcal{E}C}{L}$

(E) $\frac{\mathcal{E}L}{C}$

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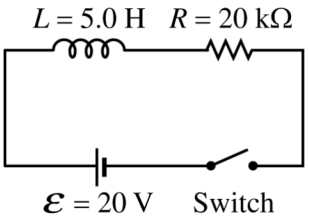
Questions 22-23



After the switch is closed in the circuit above, the current in the circuit is given by $i = I\left(1 - e^{-t/\tau}\right)$, where I and τ are constants.

22. What is the value of I ?

(A) 0
(B) 0.001 A
(C) 0.80 A
(D) 1.0 A
(E) 4.0 A

23. What is the value of τ ?

(A) 1.0×10^{-5} s
(B) 2.5×10^{-4} s
(C) 1.0 s
(D) 4.0×10^{3} s
(E) 1.0×10^{5} s

24. Two stationary point charges of unknown magnitude and sign are isolated from all other charges. If the electric field strength is zero at the midpoint of the line joining them, which of the following can be concluded about the charges?

(A) They are equal in magnitude but opposite in sign.
(B) They are equal in magnitude and have the same sign.
(C) They are not necessarily equal in magnitude but have opposite signs.
(D) They are not necessarily equal in magnitude but have the same sign.
(E) None of the above can be concluded without additional information.

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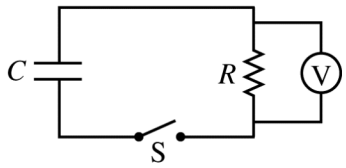
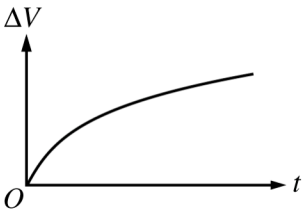
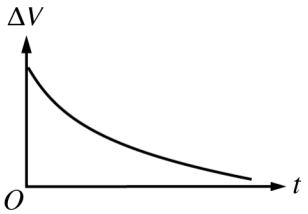
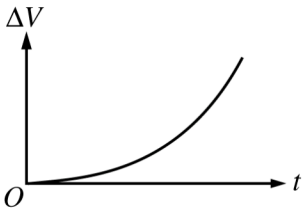
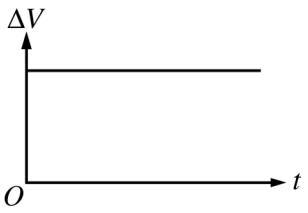


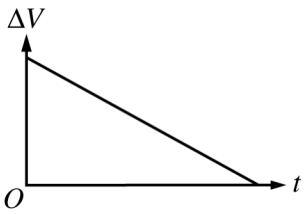
25. A charged capacitor C, resistor R, and switch S are connected in series. Voltmeter V is connected in parallel with the resistor, as shown in the figure above. At time $t = 0$, the switch is then closed. Which of the following shows the potential difference ΔV reading on the voltmeter as a function of time t after the switch is closed?

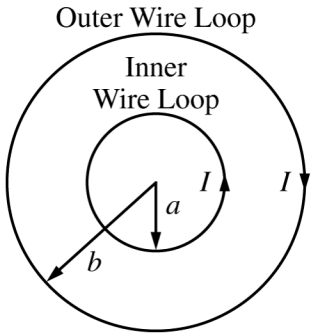
(A)


(B)


(C)


(D)


(E)




26. Two concentric circular wire loops carry equal currents I in opposite directions, as shown in the figure above. The inner loop has a radius a and carries a counterclockwise current. The outer loop has a radius b and carries a clockwise current. What is the magnitude and direction of the magnetic field at the center of the loops?

	Magnitude	Direction
(A)	$\frac{\mu_0 I}{2}\left(\frac{1}{a}-\frac{1}{b}\right)$	Out of the page
(B)	$\frac{\mu_0 I}{2}\left(\frac{1}{a}-\frac{1}{b}\right)$	Into the page
(C)	Zero	Undefined since magnitude is zero
(D)	$\frac{\mu_0 I}{2\pi}\left(\frac{1}{a}-\frac{1}{b}\right)$	Out of the page
(E)	$\frac{\mu_0 I}{2\pi}\left(\frac{1}{a}-\frac{1}{b}\right)$	Into the page

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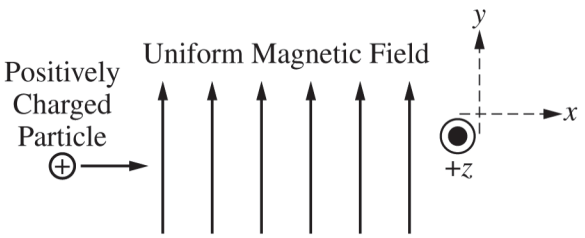
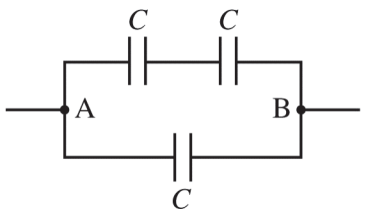


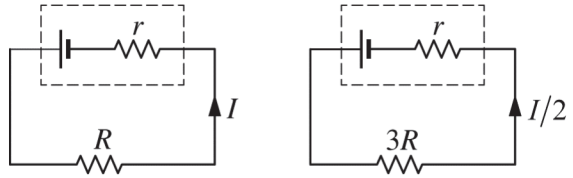
27. A positively charged particle moves in the positive x-direction in a uniform magnetic field directed in the positive y-direction. The net force on the particle could be zero if there is also an electric field present in the

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



28. Three identical capacitors with capacitance C are arranged as shown above. What is the equivalent capacitance between points A and B?

(A) $C/3$
(B) $2C/3$
(C) C
(D) $3C/2$
(E) $3C$



29. When a battery is connected to an external resistance R, as shown above on the left, there is a current I in the circuit. When the external resistance is changed to $3R$, the current changes to $I/2$, as shown above on the right. What is the internal resistance r of the battery?

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

30. The advantage of using a dielectric in a capacitor is that it

(A) increases the capacitance of the capacitor
(B) increases the conductivity of the capacitor
(C) decreases the charging time of the capacitor
(D) makes the capacitor dissipate less power
(E) eliminates the electric field in the capacitor

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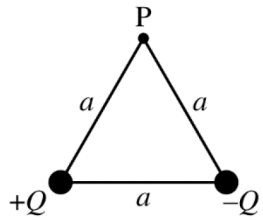
Questions 31-33



Two small spheres have charges $+Q$ and $-Q$ and are located at the bottom corners of an equilateral triangle, as shown in the figure above. The equilateral triangle has sides of length a, and point P is at the top corner of the triangle.

31. The potential energy stored in the charge configuration shown is

(A) $\frac{Q^2}{4\pi\varepsilon_0 a}$

(B) $\frac{Q}{4\pi\varepsilon_0 a^2}$

(C) zero

(D) $-\frac{Q}{4\pi\varepsilon_0 a^2}$

(E) $-\frac{Q^2}{4\pi\varepsilon_0 a}$

32. The electric potential at point P due to the two spheres is

(A) zero

(B) $\frac{Q}{4\pi\varepsilon_0 a}$

(C) $\frac{Q}{4\pi\varepsilon_0 a^2}$

(D) $\frac{2Q}{4\pi\varepsilon_0 a}$

(E) $\frac{2Q}{4\pi\varepsilon_0 a^2}$

33. The direction of the electric field at point P due to the two spheres is

(A) to the left
(B) to the right
(C) toward the bottom of the page
(D) toward the top of the page
(E) undefined, because the magnitude of the electric field at point P is zero

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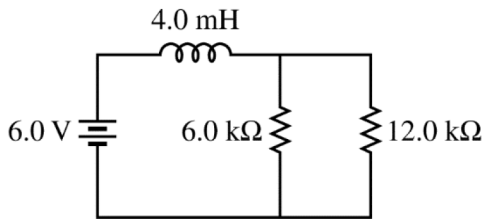
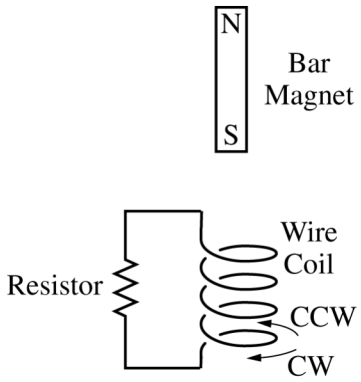


34. An inductor and two resistors are connected to an ideal battery, as shown in the figure above. What is the time constant for the circuit?

(A) 0.22 μs
(B) 0.33 μs
(C) 0.67 μs
(D) 1.0 μs
(E) 72 μs



35. A bar magnet with its south pole pointing down is released from rest and falls through a wire coil, as shown above. A resistor is connected across the two ends of the coil. What current would be produced in the coil, as observed by a person directly above the coil?

(A) A clockwise current only
(B) A counterclockwise current only
(C) A current that is first clockwise and then counterclockwise
(D) A current that is first counterclockwise and then clockwise
(E) No current would be produced.

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GO ON TO THE NEXT PAGE.

S T O P

END OF ELECTRICITY AND MAGNETISM SECTION I

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

DO NOT TURN TO ANY OTHER TEST MATERIALS.

MAKE SURE YOU HAVE DONE THE FOLLOWING.

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

Section II: Free-Response Questions

This is the free-response section of the 2018 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

2018

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 4OBP4-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,	$1\text{ u} = 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\varepsilon_0 = 8.85 \times 10^{-12}$ $\text{C}^2/\left(\text{N}\cdot\text{m}^2\right)$
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,	$1\text{ atm} = 1.0 \times 10^{5}$ 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
$\mathcal{E}$ = 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

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

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

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

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

$B_s = \mu_0 n I$

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

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

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

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

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

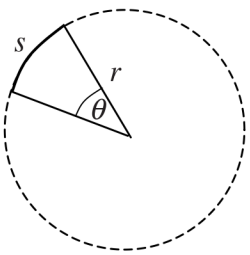
$a^2 + b^2 = c^2$

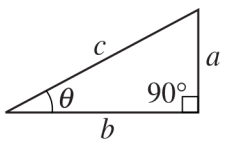
$\sin\theta = \frac{a}{c}$

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

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

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

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

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

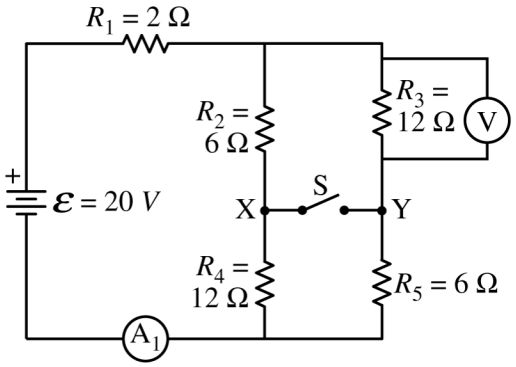
PHYSICS C: ELECTRICITY AND MAGNETISM

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. A circuit is created with an ideal battery and five resistors with the values shown in the figure above. An open switch is shown that can connect points X and Y. A voltmeter V and an ammeter A_1 are also shown in the figure.

   (a) The switch is in the open position.

   i. Calculate the current measured by the ammeter A_1.

   ii. Calculate the potential difference measured by the voltmeter V.

   (b) The switch is now moved to the closed position.

   i. Calculate the current measured by the ammeter A_1.

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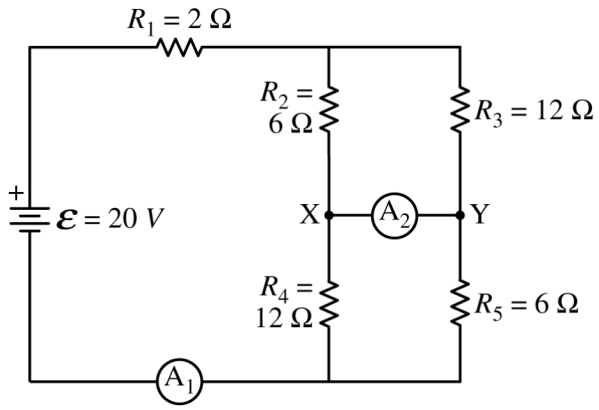
GO ON TO THE NEXT PAGE.

ii. Calculate the potential difference measured by the voltmeter V.

A student wants to determine if there is a current in the closed switch. The switch is now replaced with ammeter A_2 between points X and Y. The ammeter acts as a closed switch and can measure the current, if any, between the two points.



(c)

i. Calculate the current measured by ammeter A_2.

ii. Indicate the direction of the current, if any, through the ammeter A_2.

____ Left ____ Right ____ Undefined, because the current is zero

Question 1 continues on the next page.

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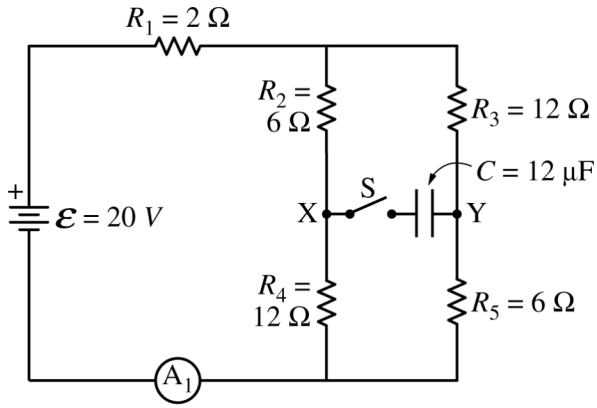

(d) The ammeter A_2 is replaced with switch S and capacitor $C = 12\ \mu F$, as shown in the figure above. Switch S is closed.

i. Calculate the charge stored on the positive plate of capacitor C a long time after switch S is closed.

ii. Which point, X or Y, is at a higher electric potential?

____ X ____ Y

Justify your answer.

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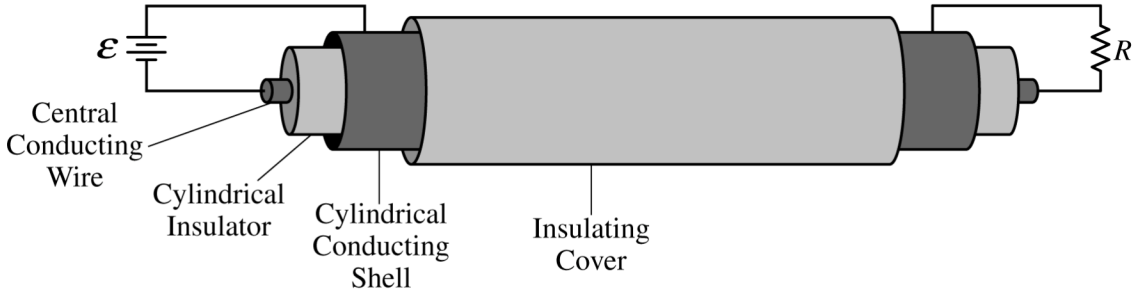
GO ON TO THE NEXT PAGE.



Schematic Diagram



Circuit Figure

2. A coaxial cable is composed of a central conducting wire surrounded by a cylindrical insulator, and around that is a conducting cylindrical shell with an insulating cover. A power supply of emf $\mathcal{E}$ is used at one end to connect the two conducting regions, and a resistive load of resistance R is connected at the other end of the cable to complete the circuit, as shown in the schematic diagram and circuit figure above.

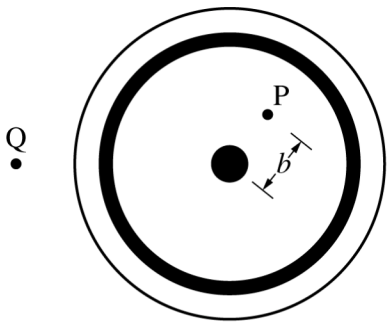


Figure 1

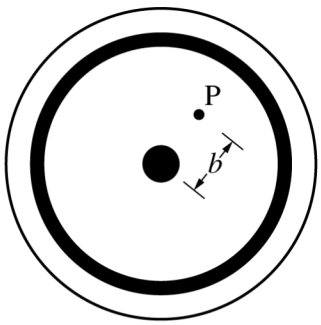


Figure 2

A cross section of the cable from the perspective of the power supply end is depicted above as if looking into the left end of the cable. Point P is inside the cylindrical insulator a distance b from the center of the cable. Point Q is outside the cable.

(a)

i. On figure 1 shown above left, draw an Amperian loop that could be used to determine the magnitude of the magnetic field at point P in the diagram. Clearly mark this loop as "Loop 1."

ii. On figure 1, draw an Amperian loop that could be used to determine the magnitude of the magnetic field at point Q in the diagram. Clearly mark this loop as "Loop 2."

iii. On figure 2 shown above right, draw an arrow to show the direction of the magnetic field at point P. The arrow should start on and point away from the point in the direction of the magnetic field.

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GO ON TO THE NEXT PAGE.

(b) Using Ampere's law, derive an expression for the magnitude of the magnetic field at point P. Express your answer in terms of $\mathcal{E}$, R, b, and physical constants, as appropriate.

(c) Determine the magnitude of the magnetic field at point Q.

Justify your answer.

Question 2 continues on the next page.

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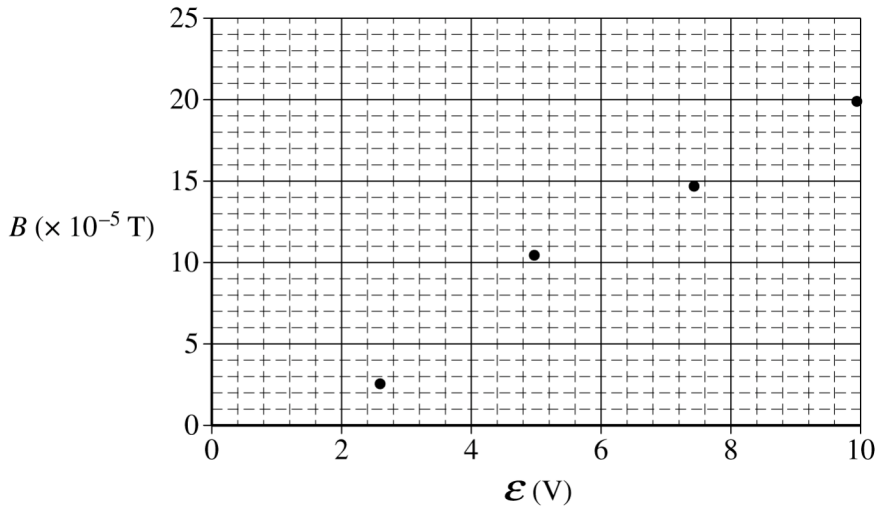
Some physics students conduct an experiment with a coaxial cable in which they connect the cable to a variable power supply and measure the resulting magnetic field strength at point P inside the cylindrical insulator using a magnetic field sensor. Point P is 0.0050 m from the center of the cable. The plot of the magnetic field strength B as a function of the emf $\mathcal{E}$ of the power supply is shown below.



(d)

i. Draw the best-fit line for the data.

ii. Use the straight line to calculate the resistance R of the resistor used in the experiment.

(e) The lab group uses a multimeter to measure the resistance of the resistor and determines that their experimental value for R from part (d) is approximately 10% larger than that found with the multimeter. Describe a physical reason that might account for this result.

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(f) The lab group notices that when the current is reversed in the cable and the experiment is again performed, the plot has a positive vertical axis intercept equal in magnitude to the negative vertical axis intercept in the plot shown before part (d).

i. Describe a physical reason for the vertical axis intercept.

ii. Describe a physical reason that the vertical axis intercept switches from negative to positive when the current in the cable is reversed.

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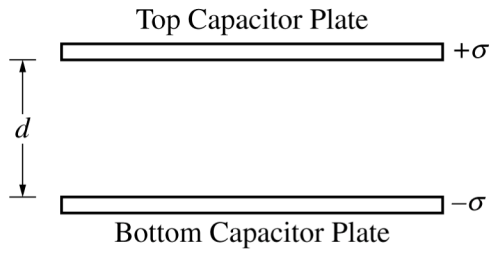

Note: Figure not drawn to scale.

3. A parallel plate capacitor is connected to a battery, fully charged, and then isolated from the battery. The plates are given equal and opposite charge densities σ, and the separation between the plates is d, as shown in the figure above. The area of each plate has a value of A.

   (a) Derive an expression for the energy stored in the capacitor. Express your answer in terms of σ, d, A, and physical constants, as appropriate.



While the capacitor is isolated from the battery, an uncharged metal slab of thickness x and area A is inserted between the capacitor plates so that it is an equal distance from the two plates, as shown in the figure above.

   (b) On the figure above, draw an arrow to indicate the direction of the electric field in the following three regions of space between the capacitor plates. If the electric field is zero in any region, indicate this by writing "$E = 0$" in that region.

      i. The region between the top plate and the metal slab

      ii. The region inside the metal slab

      iii. The region between the metal slab and the bottom plate

   (c) On the lines below, rank the regions according to the magnitude of the electric field, with 1 being the largest magnitude. If any regions have the same magnitude of electric field, give them the same ranking.

      ____ The region between the top plate and the metal slab

      ____ The region inside the metal slab

      ____ The region between the metal slab and the bottom plate

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GO ON TO THE NEXT PAGE.

(d) Is the capacitance of the capacitor with the metal slab greater than, less than, or equal to the capacitance of the original capacitor without the slab?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

(e) When charged to the original charge density, is the energy stored in the capacitor with the metal slab greater than, less than, or equal to the original energy stored in the capacitor calculated in part (a) ?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

Question 3 continues on the next page.

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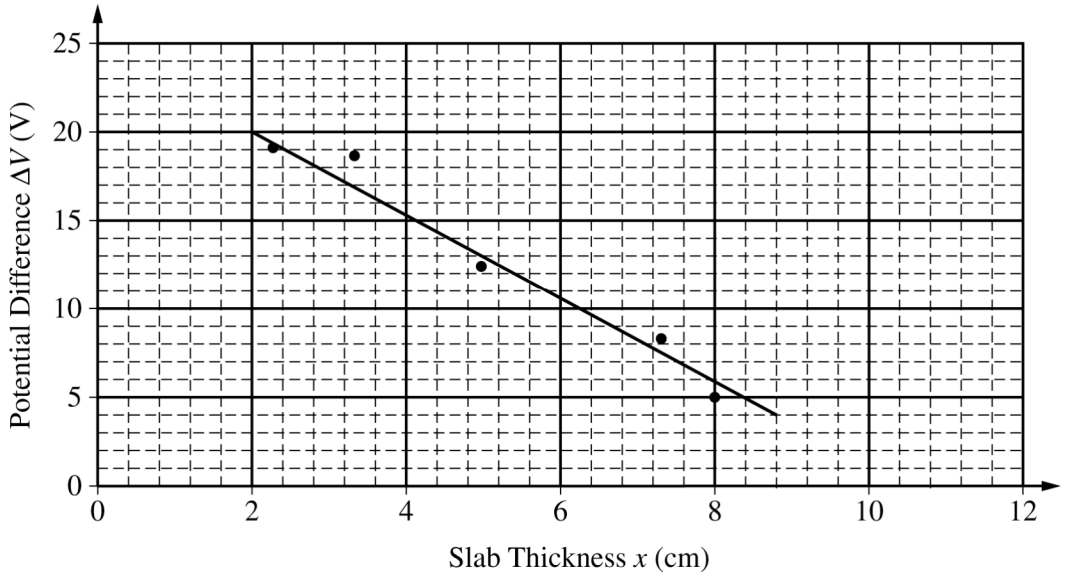
Some physics students conduct an experiment in which they charge the capacitor to the same potential difference, isolate it from the battery, insert the metal slab, and measure the new potential difference across the capacitor. This experiment is repeated with slabs of different thickness. The plot of the potential difference ΔV across the capacitor as a function of the thickness x of the slab is shown below. A best-fit line for the data has been drawn.



(f) Use the best-fit line to calculate the following:

i. σ, the charge density on the plates

ii. d, the distance between the capacitor plates

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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: C

Question 2: A

Question 3: D

Question 4: E

Question 5: B

Question 6: C

Question 7: C

Question 8: C

Question 9: A

Question 10: B

Question 11: E

Question 12: E

Question 13: C

Question 14: C

Question 15: A

Question 16: E

Question 17: D

Question 18: B

Question 19: C

Question 20: D

Question 21: B

Question 22: B

Question 23: B

Question 24: B

Question 25: B

Question 26: A

Question 27: B

Question 28: D

Question 29: C

Question 30: A

Question 31: E

Question 32: A

Question 33: B

Question 34: D

Question 35: C

Free-Response Scoring Guidelines

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

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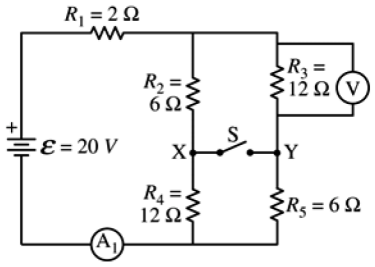
Question 1

15 points total **Distribution of points**



A circuit is created with an ideal battery and five resistors with the values shown in the figure above. An open switch is shown that can connect points X and Y. A voltmeter V and an ammeter A_1 are also shown in the figure.

(a) The switch is in the open position.

i) 3 points

Calculate the current measured by the ammeter A_1.

For correct equivalent resistance of the circuit		1 point
$R_{24} = R_2 + R_4 = 6\ \Omega + 12\ \Omega = 18\ \Omega$		
$R_{35} = R_3 + R_5 = 12\ \Omega + 6\ \Omega = 18\ \Omega$		
$\frac{1}{R_P} = \frac{1}{R_{24}} + \frac{1}{R_{35}} = \frac{1}{18\ \Omega} + \frac{1}{18\ \Omega} = \frac{2}{18\ \Omega} = \frac{1}{9\ \Omega} \therefore R_P = 9\ \Omega$		
$R_{EQ} = R_1 + R_P = 2\,\Omega + 9\,\Omega = 11\,\Omega$		
For consistent substitution into a correct equation (i.e., Ohm's law or Kirchhoff's law)		1 point
$I = \frac{V}{R} = \frac{(20\ \text{V})}{(11\ \Omega)}$		
For the correct answer with the units		1 point
$I = 1.82\,A$		

ii) 1 point

Calculate the potential difference measured by the voltmeter V.

For correct substitution (consistent with a(i)) into a correct equation to calculate the potential difference across R_3		1 point
$V_P = \mathcal{E} - V_1 = \mathcal{E} - IR_1 = (20\ \text{V}) - (1.82\ \text{A})(2\ \Omega) = 16.4\ \text{V}$		
$I_{35} = \frac{V_P}{R_{35}} = \frac{(16.4\ \text{V})}{(18\ \Omega)} = 0.91\ \text{A}$		
$V_3 = I_{35}R_3 = (0.91\ \text{A})(12\ \Omega) = 10.9\ \text{V}$		

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Question 1 (continued)

Distribution of points

(b) The switch is now moved to the closed position.

i) 3 points

Calculate the current measured by the ammeter A_1.

For the correct equivalent resistance of the circuit		1 point
$\frac{1}{R_{23}} = \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{6\ \Omega} + \frac{1}{12\ \Omega} = \frac{3}{12\ \Omega} = \frac{1}{4\ \Omega} \therefore R_{23} = 4\ \Omega$		
$\frac{1}{R_{45}} = \frac{1}{R_4} + \frac{1}{R_5} = \frac{1}{12\ \Omega} + \frac{1}{6\ \Omega} = \frac{3}{12\ \Omega} = \frac{1}{4\ \Omega} \therefore R_{45} = 4\ \Omega$		
$R_S = R_{23} + R_{45} = 4\ \Omega + 4\ \Omega = 8\ \Omega$		
$R_{EQ} = R_1 + R_S = 2\,\Omega + 8\,\Omega = 10\,\Omega$		
For consistent substitution into a correct equation (i.e., Ohm's law or Kirchhoff's law)		1 point
$I = \frac{V}{R} = \frac{(20\ \text{V})}{(10\ \Omega)}$		
For the correct answer with the units		1 point
$I = 2.0\ \text{A}$		

ii) 1 points

Calculate the potential difference measured by the voltmeter V.

For correct substitution (consistent with b(i)) into a correct equation to calculate the potential difference across R_3		1 point
$V_{23} = IR_{23} = (2.0\ \text{A})(4\ \Omega) = 8\ \text{V}$		

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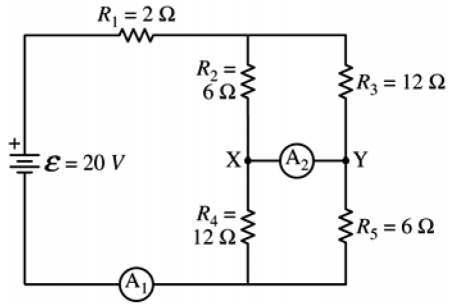
Question 1 (continued)

Distribution of points

A student wants to determine if there is a current in the closed switch. The switch is now replaced with ammeter A_2 between points X and Y. The ammeter acts as a closed switch and can measure the current, if any, between the two points.



(c)

i) 2 points

Calculate the current measured by ammeter A_2.

For using a correct equation to calculate the current through R_2 and R_4 (or R_3 and R_5)		1 point
$I_2 = \frac{V_{23}}{R_2} = \frac{(8\ \text{V})}{(6\ \Omega)} = 1.33\ \text{A}$		
$I_4 = \frac{V_{45}}{R_4} = \frac{\mathcal{E} - V_1 - V_{23}}{R_4} = \frac{\mathcal{E} - IR_1 - V_{23}}{R_4} = \frac{(20\ \text{V}) - (2\ \text{A})(2\ \Omega) - (8\ \text{V})}{(12\ \Omega)} = 0.67\ \text{A}$		
For indicating that the current through the ammeter is the difference between the currents through the two resistors		1 point
$I_A = I_2 - I_4 = (1.33\ \text{A}) - (0.67\ \text{A}) = 0.67\ \text{A}$		

ii) 1 point

Indicate the direction of the current, if any, through the ammeter A_2.

____ Left ____ Right ____ Undefined, because the current is zero

For selecting "Right" Note: If a student calculated I_A in Part c(i) to be zero then the consistent answer of "Undefined" earns 1 point.		1 point

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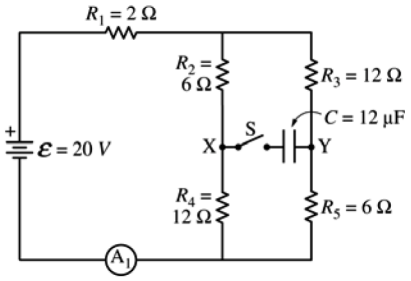
Question 1 (continued)

Distribution of points



(d) The ammeter A_2 is replaced with switch S and capacitor $C = 12\ \mu F$, as shown in the figure above. Switch S is closed.

i) 3 points

Calculate the charge stored on the positive plate of capacitor C a long time after switch S is closed.

For calculating the potential at points X and Y		1 point
$I_{24} = \frac{V_P}{R_{24}} = \frac{(16.4\ V)}{(18\ \Omega)} = 0.91\ A$		
$V_2 = I_{24}R_2 = (0.91\ A)(6\ \Omega) = 5.5\ V$		
$V_X = \mathcal{E} - V_1 - V_2 = (20\ V) - (1.82\ A)(2\ \Omega) - (5.5\ V) = 10.9\ V$		
$V_Y = \mathcal{E} - V_1 - V_3 = (20\ V) - (1.82\ A)(2\ \Omega) - (10.9\ V) = 5.5\ V$		
For indicating that the potential difference across the capacitor is the difference in potential at points X & Y		1 point
$V_C = V_X - V_Y = (10.9\ V) - (5.5\ V) = 5.4\ V$		
For substituting into the equation for the charge stored on the capacitor		1 point
$Q = CV = (12\ \mu F)(5.4\ V) = 65.3\ \mu C$		

ii) 1 point

Which point, X or Y, is at a higher electric potential?

____ X ____ Y

Justify your answer.

Selecting "X"		
For a correct justification		1 point
Example: The point X is at higher potential because the current flows to the right. The current flows from high potential to low potential. *Example: The potential at X is 10.9 V and the potential at Y is 5.5 V. So point X is at the higher potential.*		

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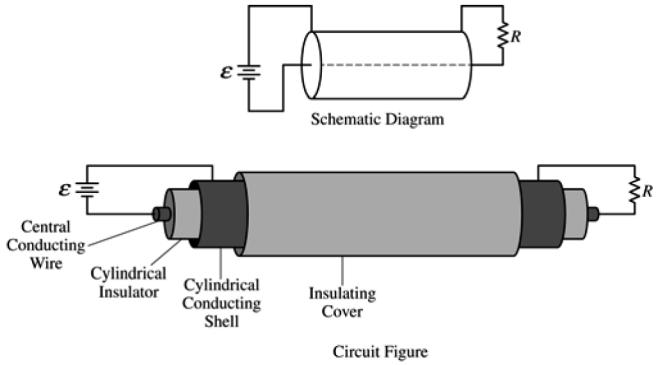
Question 2

15 points total **Distribution of points**



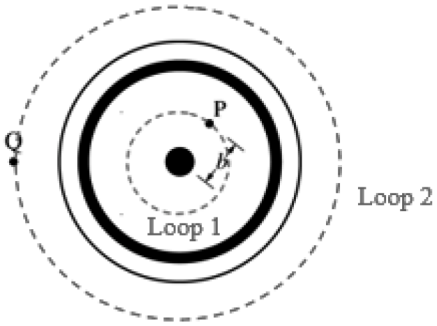
A coaxial cable is composed of a central conducting wire surrounded by a cylindrical insulator, and around that is a conducting cylindrical shell with an insulating cover. A power supply of emf $\mathcal{E}$ is used at one end to connect the two conducting regions, and a resistive load of resistance R is connected at the other end of the cable to complete the circuit, as shown in the schematic diagram and circuit figure above.

A cross section of the cable from the perspective of the power supply end is depicted above as if looking into the left end of the cable. Point P is inside the cylindrical insulator a distance b from the center of the cable. Point Q is outside the cable.

(a)

i) 1 point

On figure 1 shown above left, draw an Amperian loop that could be used to determine the magnitude of the magnetic field at point P in the diagram. Clearly mark this loop as "Loop 1."



For properly drawing and labeling a circle concentric with the other circles and through point P		1 point

ii) 1 point

On figure 1, draw an Amperian loop that could be used to determine the magnitude of the magnetic field at point Q in the diagram. Clearly mark this loop as "Loop 2."

For properly drawing and labeling a circle concentric with the other circles and through point Q		1 point

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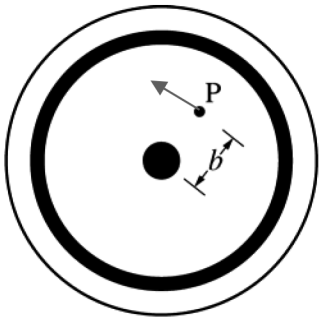
Question 2 (continued)

Distribution of points

(a) Con't

iii) 2 points

On figure 2 shown above right, draw an arrow to show the direction of the magnetic field at point P. The arrow should start on and point away from the point in the direction of the magnetic field.



For properly drawing a straight arrow at point P that indicates the magnetic field is tangent to Loop 1 from part (a)(i)		1 point
For indicating a counter-clockwise magnetic field around Loop 1 from part (a)(i)		1 point

(b) 3 points

Using Ampere's law, derive an expression for the magnitude of the magnetic field at point P. Express your answer in terms of ε , R, b, and physical constants, as appropriate.

For using Ampere's law at point P		1 point
$\oint \vec{B} d\vec{\ell} = \mu_0 I$		
For correctly substituting for $\oint d\vec{l}$		1 point
$B(2\pi b) = \mu_0 I$		
For correctly substituting for I		1 point
$B(2\pi b) = \mu_0 \frac{\varepsilon}{R} \therefore B = \frac{\mu_0 \varepsilon}{2\pi b R}$		

(c) 2 points

Determine the magnitude of the magnetic field at point Q.
Justify your answer.

For indictaing that the magnetic field at point Q is zero		1 point
For a correct justification		1 point
Example: Since Loop 2 encloses both the inside wire and the outer conducting shell and the two of them have equal and opposite currents, the net enclosed current is zero. Thus the magnetic field at point Q is zero.		

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2018 SCORING GUIDELINES

Question 2 (continued)

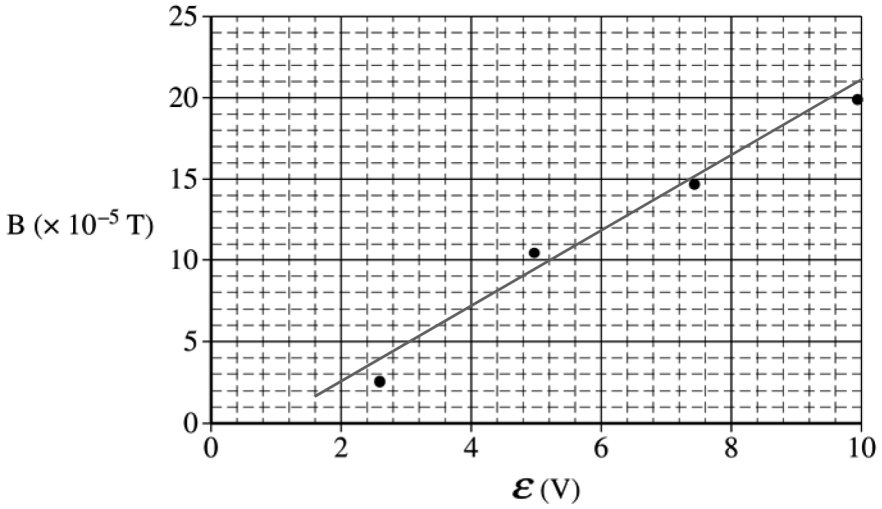
Distribution of points

Some physics students conduct an experiment with a coaxial cable in which they connect the cable to a variable power supply and measure the resulting magnetic field strength at point P inside the cylindrical insulator using a magnetic field sensor. Point P is 0.0050 m from the center of the cable. The plot of the magnetic field strength B as a function of the emf $\mathcal{E}$ of the power supply is shown below.

(d)

i) 1 point

Draw the best-fit line for the data.



For properly drawing a trend line on the graph		1 point

ii) 2 points

Use the straight line to calculate the resistance R of the resistor used in the experiment.

For correctly calculating the slope from the best-fit line and not the data points		1 point
$\text{slope} = \frac{\Delta B}{\Delta \mathcal{E}} = \frac{(20-5)\left(\text{T}\times 10^{-5}\right)}{(9.4-3.2)(\text{V})} = 2.42\times 10^{-5}\ \text{T/V}$		
For correctly relating the slope to the equation from part (b)		1 point
$\text{slope} = \frac{\mu_0}{2\pi bR} \therefore R = \frac{\mu_0}{\text{slope}\times 2\pi b} = \frac{\left(4\pi\times 10^{-7}\ \text{T•m/A}\right)}{\left(2.42\times 10^{-5}\ \text{T/V}\right)(2\pi)(0.0050\ \text{m})} = 1.65\ \Omega$		

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Question 2 (continued)

Distribution of points

(e) 1 point

The lab group uses a multimeter to measure the resistance of the resistor and determines that their experimental value for R from part (d) is approximately 10% larger than that found with the multimeter. Describe a physical reason that might account for this result.

For an appropriate explanation for the difference in the resistance values		1 point
Example: There is resistance in the wires, thereby increasing the total experimental resistance.		

(f) The lab group notices that when the current is reversed in the cable and the experiment is again performed, the plot has a positive vertical axis intercept equal in magnitude to the negative vertical axis intercept in the plot shown before part (d).

i) 1 point

Describe a physical reason for the vertical axis intercept.

For an appropriate explanation for the vertical axis intercept		1 point
Example: The magnetic field sensor was not zeroed at the start of the experiment to account for the Earth's magnetic field		

ii) 1 point

Describe a physical reason that the vertical axis intercept switches from negative to positive when the current in the cable is reversed.

For an appropriate explanation for the intercept switching from negative to positive		1 point
Example: When the current is reversed, the cable's magnetic field switches direction but the external magnetic field from the Earth remains constant.		

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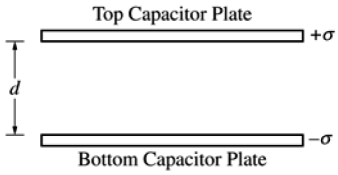
Question 3

15 points total **Distribution of points**



Note: Figure not drawn to scale.

A parallel plate capacitor is connected to a battery, fully charged, and then isolated from the battery. The plates are given equal and opposite charge densities σ, and the separation between the plates is d, as shown in the figure above. The area of each plate has a value of A.

(a) 3 points

Derive an expression for the energy stored in the capacitor. Express your answer in terms of σ, d, A, and physical constants, as appropriate.

For using an appropriate equation for calculating the energy stored in a capacitor		1 point
$U = \frac{q^2}{2C}$		
For substituting correctly into above equation		1 point
$U = \frac{(\sigma A)^2}{2\frac{\varepsilon_0 A}{d}}$		
For a correct answer		1 point
$U = \frac{dA\sigma^2}{2\varepsilon_0}$		

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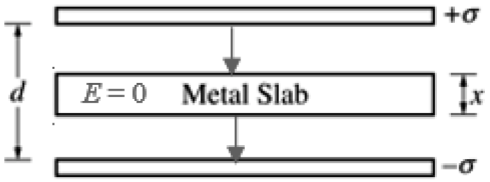
Question 3 (continued)

Distribution of points

While the capacitor is isolated from the battery, an uncharged metal slab of thickness x and area A is inserted between the capacitor plates so that it is an equal distance from the two plates, as shown in the figure above.

(b) On the figure above, draw an arrow to indicate the direction of the electric field in the following three regions of space between the capacitor plates. If the electric field is zero in any region, indicate this by writing "$E = 0$" in that region.



i) 1 point

The region between the top plate and the metal slab

For properly drawing an arrow between the top plate and the metal slab pointing downward		1 point

ii) 1 point

The region inside the metal slab

For indicating that $E = 0$ inside the metal slab		1 point

iii) 1 point

The region between the metal slab and the bottom plate

For properly drawing an arrow between the metal slab and the bottom plate pointing downward		1 point

(c) 1 point

On the lines below, rank the regions according to the magnitude of the electric field, with 1 being the largest magnitude. If any regions have the same magnitude of electric field, give them the same ranking.

____ The region between the top plate and the metal slab

____ The region inside the metal slab

____ The region between the metal slab and the bottom plate

For ranking both regions between a plate and the metal slab as 1 and the region inside the metal slab as 2		1 point

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Question 3 (continued)

Distribution of points

(d) 2 points

Is the capacitance of the capacitor with the metal slab greater than, less than, or equal to the capacitance of the original capacitor without the slab?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

For selecting "Greater than" with an attempt at a relevant justification		1 point
For a correct justification		1 point
Example: Inserting the metal slab effectively decreases the distance over which the electric field exists in the capacitor. Since the distance between the plates is effectively smaller, the capacitance is increased.		
Example: Inserting the metal slab decreases the extent of the electric field between the plates, which lowers the electric potential. If the electric potential between plates of a capacitor is lowered and the charge remains constant, the capacitance is increased.		

(e) 2 points

When charged to the original charge density, is the energy stored in the capacitor with the metal slab greater than, less than, or equal to the original energy stored in the capacitor calculated in part (a) ?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

For selecting "Less than" with an attempt at a relevant justification or for selecting an answer consistent with part (d)		1 point
For a correct justification		1 point
Example: Since the equivalent capacitance with the slab is greater than the original capacitance, and the energy stored is related to capacitance by $U = q^2/(2C)$*, the energy stored on the capacitor will be less with the metal slab.*		

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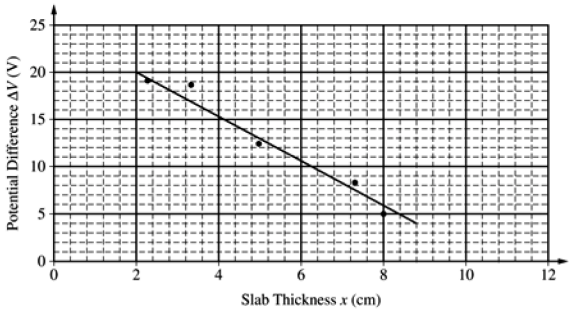
Question 3 (continued)

Distribution of points

Some physics students conduct an experiment in which they charge the capacitor to the same potential difference, isolate it from the battery, insert the metal slab, and measure the new potential difference across the capacitor. This experiment is repeated with slabs of different thickness. The plot of the potential difference ΔV across the capacitor as a function of the thickness x of the slab is shown below. A best-fit line for the data has been drawn.



(f) Use the best-fit line to calculate the following:

i) 2 points

σ, the charge density on the plate

For correctly calculating the slope using appropriate values from the best-fit line		1 point
$\text{slope} = \dfrac{\Delta V}{\Delta x} = \dfrac{(15-5)(\text{V})}{(4.1-8.4)\left(\times 10^{-2}\ \text{m}\right)} = -232\ \text{V/m}$		
For correctly relating the slope to the charge density on the plates		1 point
$\text{slope} = -\dfrac{\sigma}{\varepsilon_0} \therefore \sigma = -\text{slope} \times \varepsilon_0 = -(-232\ \text{V/m})\left(8.85 \times 10^{-12}\ \text{C}^2/\left(\text{N}\cdot\text{m}^2\right)\right)$		
$\sigma = 2.06 \times 10^{-9}\ \text{C/m}^2$		

ii) 2 points

d, the distance between the capacitor plates

For appropriately using the best fit line		1 point
$V = \dfrac{\sigma(d-x)}{\varepsilon_0} \therefore (d-x) = \dfrac{V\varepsilon_0}{\sigma} \therefore d = x + \dfrac{V\varepsilon_0}{\sigma}$		
For an answer, with units, consistent with the charge density found above		1 point
$d = 0.02\ \text{m} + \dfrac{(20\ \text{V})\left(8.85 \times 10^{-12}\ \text{C}^2/\left(\text{N}\cdot\text{m}^2\right)\right)}{\left(2.06 \times 10^{-9}\ \text{C/m}^2\right)}$		
$d = 10.6\ \text{cm}$		

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Question 3 (continued)

Distribution of points

(f) con't

ii) con't

Alternate solution		*Alternate points*
For using the extension of the best fit line to the x-axis		*1 point*
For an answer, with units, consistent with the extension of the line		*1 point*
$d = 10.6$ cm		

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Scoring Worksheet

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

2018 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
51-90	5
40-50	4
33-39	3
22-32	2
0-21	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.

2018 AP Physics C: Electricity and Magnetism Question Descriptors and Performance Data

Multiple-Choice Questions

Questions	Topic	Key	% Correct
1	Electrostatics	C	29
2	Electrostatics	A	40
3	Conductors/capacitors/dielectrics	D	40
4	Electrostatics	E	64
5	Electromagnetism	B	40
6	Electromagnetism	C	51
7	Electromagnetism	C	69
8	Conductors/capacitors/dielectrics	C	50
9	Electrostatics	A	79
10	Electrostatics	B	65
11	Electrostatics	E	49
12	Electromagnetism	E	46
13	Electromagnetism	C	43
14	Magnetostatics	C	59
15	Magnetostatics	A	65
16	Magnetostatics	E	39
17	Electrostatics	D	53
18	Electrostatics	B	76
19	Magnetostatics	C	62
20	Electromagnetism	D	65
21	Electromagnetism	B	24
22	Electromagnetism	B	58
23	Electromagnetism	B	59
24	Electrostatics	B	69
25	Electric circuits	B	71
26	Magnetostatics	A	19
27	Magnetostatics	B	63
28	Electric circuits	D	73
29	Electric circuits	C	62
30	Conductors/capacitors/dielectrics	A	86
31	Electrostatics	E	43
32	Electrostatics	A	50
33	Electrostatics	B	74
34	Electromagnetism	D	61
35	Electromagnetism	C	42

AP Physics C: Electricity and Magnetism

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