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<br>Calculator Allowed<br>**Number of Questions:** 35<br>*(The number of questions may vary slightly depending on the form of the exam.)*<br>**Percent of Total Score:** 50%<br>**Writing Instrument:** Pencil required |
| **Section II** | **Total Time:** 45 minutes<br>Calculator Allowed<br>**Number of Questions:** 3<br>**Percent of Total Score:** 50%<br>**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.

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## 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.)

# 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<br>(A) state<br>(B) city<br>(C) country<br>(D) continent<br>(E) village | Ⓐ ● Ⓒ Ⓓ Ⓔ |

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

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

**Form I**
**Form Code 4OBP4-S**

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| 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, $1 \text{ u} = 1.66 \times 10^{-27} \text{ kg} = 931 \text{ MeV}/c^2$

Planck's constant, $h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s

$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm

Vacuum permittivity, $\varepsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\left(\text{N}\cdot\text{m}^2\right)$

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

Vacuum permeability, $\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A

Magnetic constant, $k' = \mu_0/(4\pi) = 1 \times 10^{-7}$ (T·m)/A

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

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

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

| VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES | | | | | | | |
|---|---|---|---|---|---|---|---|
| $\theta$ | 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.

## 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
$\ell$ = 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
$\mu$ = coefficient of friction
$\theta$ = angle
$\tau$ = torque
$\omega$ = angular speed
$\alpha$ = angular acceleration
$\phi$ = 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
$\ell$ = length
$n$ = number of loops of wire per unit length
$N$ = number of charge carriers per unit volume
$P$ = power
$Q$ = charge
$q$ = point charge
$R$ = resistance
$r$ = radius or distance
$t$ = time
$U$ = potential or stored energy
$V$ = electric potential
$v$ = velocity or speed
$\rho$ = resistivity
$\Phi$ = flux
$\kappa$ = dielectric constant

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

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

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

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

$B_s = \mu_0 n I$

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

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

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

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

## 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

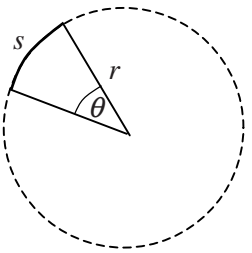
$a^2 + b^2 = c^2$

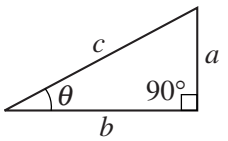
$\sin\theta = \frac{a}{c}$

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

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

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

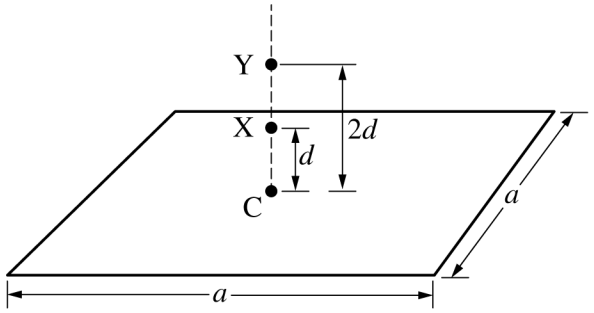
### SECTION I

**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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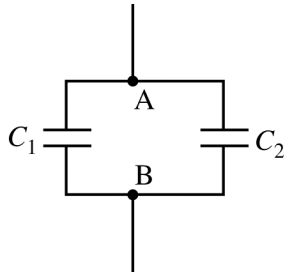


3. Capacitors $C_1$ and $C_2$ are connected as shown in the circuit above. The capacitance of $C_1$ is $C$, and the capacitance of $C_2$ is $C/3$. The equivalent capacitance between points A and B is $C_{EQ}$. A dielectric is inserted into capacitor $C_2$, and the equivalent capacitance between points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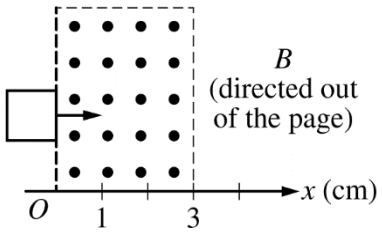
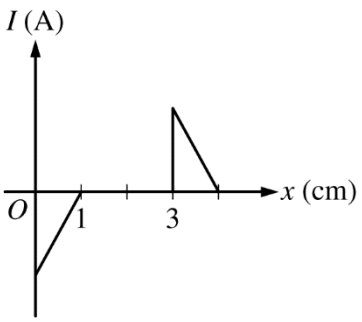
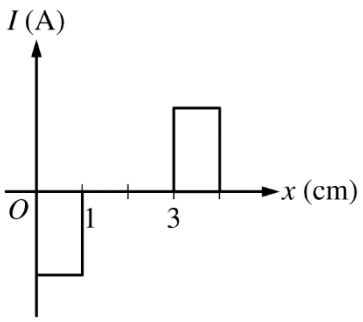
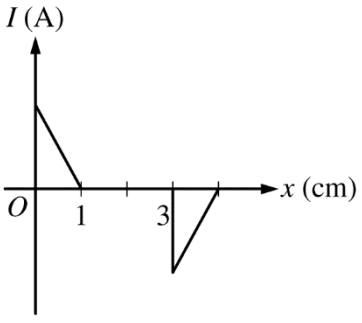
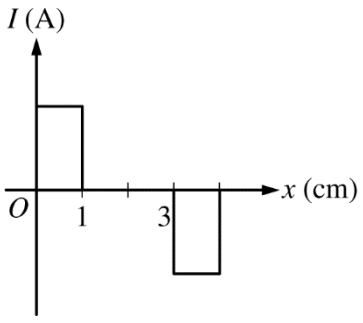


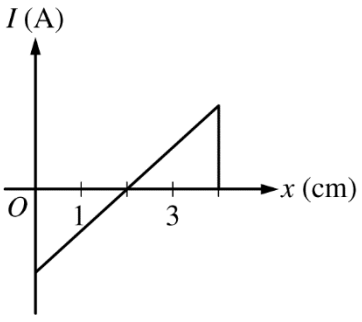

5. A square coil with sides of length 1.0 cm is moved through a region of uniform magnetic field at a constant speed, as shown in the figure above. Which of the following graphs best shows the current $I$ in the coil as a function of the position $x$ of the right edge as the coil moves through the magnetic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

(A)



(B)



(C)



(D)



(E)
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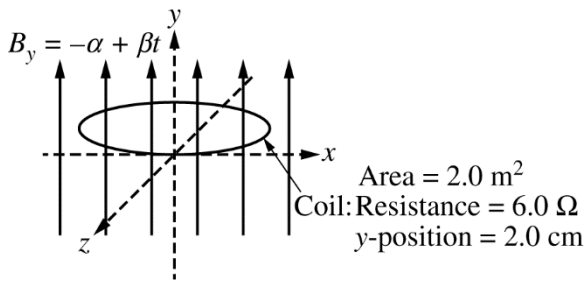
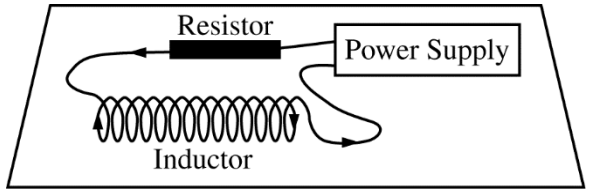



6. The $y$-component of the magnetic field $B$ is given as a function of time $t$ by the equation $B_y = -\alpha + \beta t$, where $\alpha = 4.0$ T and $\beta = 3.0$ T/s. A coil of wire with an area of $2.0\ \text{m}^2$ and a resistance of $6.0\ \Omega$ is placed in this field, parallel to the $xz$-plane 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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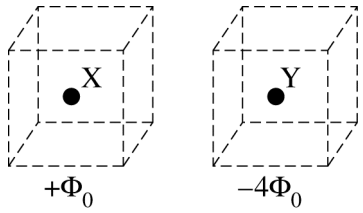
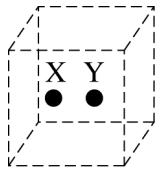
**Questions 9-11**




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?

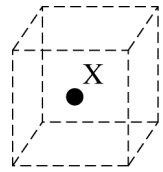
   (A) $-3\Phi_0$

   (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?

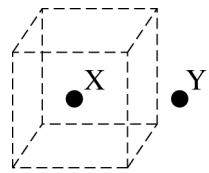
    (A) $-3\Phi_0$

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

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

    (D) $\Phi_0$

    (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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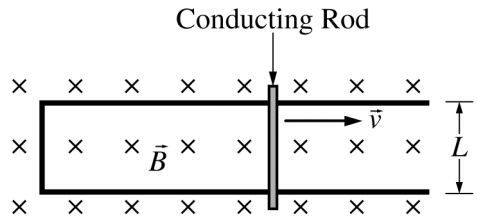

Top View

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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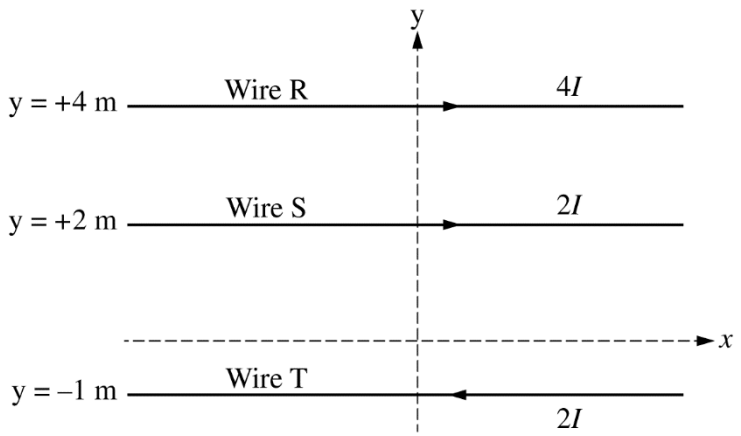


14. Three long wires, R, S, and T, are in the positions and carrying the currents indicated in the figure above. All currents are in the plane of the page and in the direction indicated. What are the magnitude and direction of the magnetic field at the origin?

| | 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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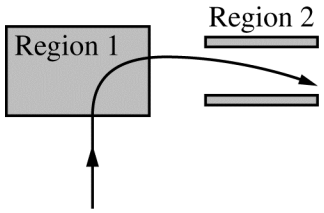
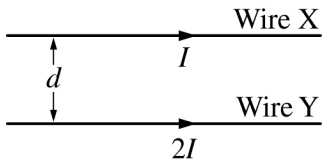



15. A positively charged particle travels along the path shown in the figure above through region 1 and between two parallel plates in region 2. A magnetic field exists in region 1, and one of the plates in region 2 is at a higher potential than the other. What is the direction of the magnetic field 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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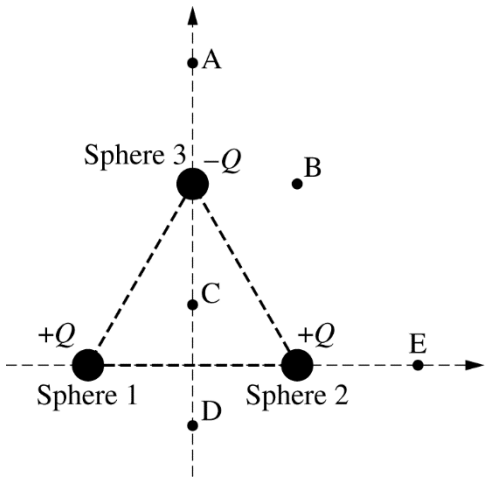
**Questions 17-18**




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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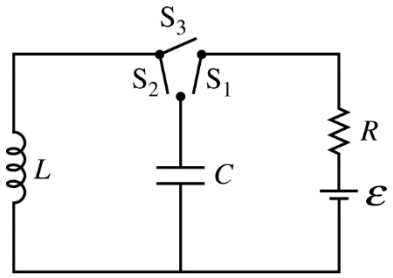
**Questions 20-21**




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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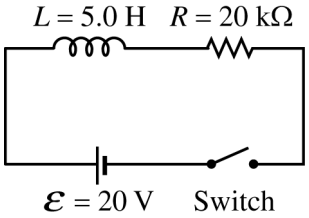
**Questions 22-23**




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 $\tau$ 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 $\tau$ ?

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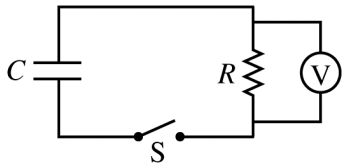
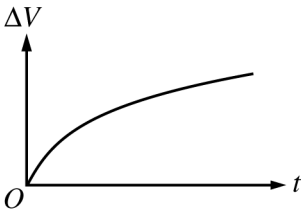
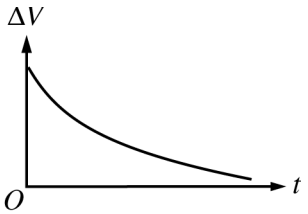
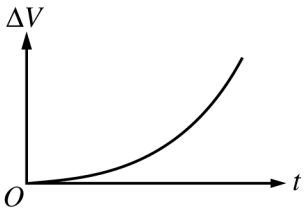
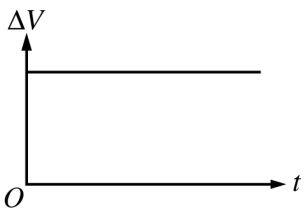


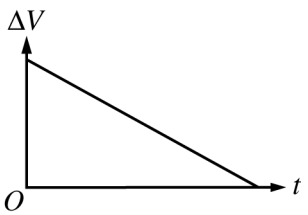

25. A charged capacitor $C$, resistor $R$, and switch S are connected in series. Voltmeter V is connected in parallel with the resistor, as shown in the figure above. At time $t = 0$, the switch is then closed. Which of the following shows the potential difference $\Delta V$ reading on the voltmeter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

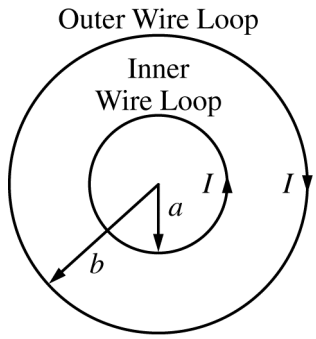
(A)



(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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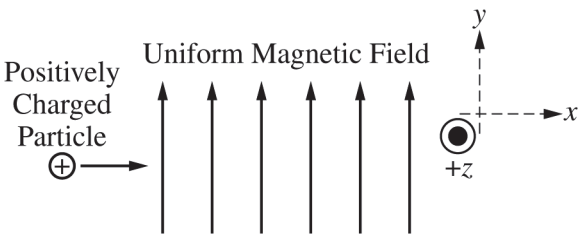
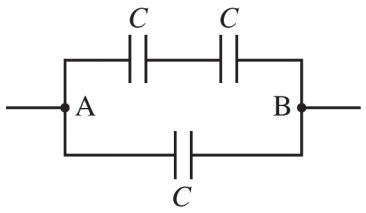


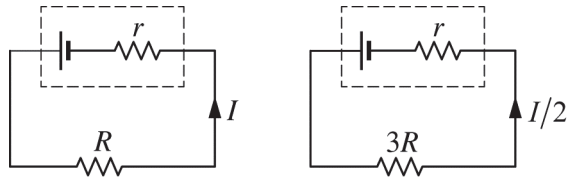

27. A positively charged particle moves in the positive $x$-direction in a uniform magnetic field directed in the positive $y$-direction. The net force on the particle could be zero if there is also an electric field present in the

(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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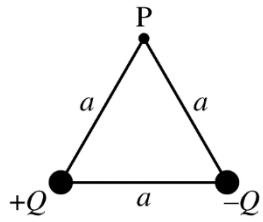
**Questions 31-33**




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) $\dfrac{Q^2}{4\pi\varepsilon_0 a}$

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

(C) zero

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

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

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

(A) zero

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

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

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

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

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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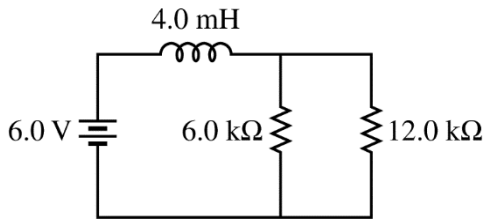
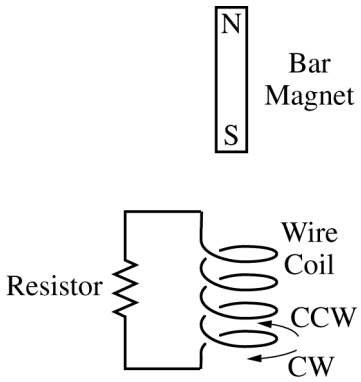



34. An inductor and two resistors are connected to an ideal battery, as shown in the figure above. What is the time constant for the circuit?

(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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# S T O P

**END OF ELECTRICITY AND MAGNETISM SECTION I**

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

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

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

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

# Section II: Free-Response Questions

This is the free-response section of the 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

| 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, $1 \text{ u} = 1.66 \times 10^{-27} \text{ kg} = 931 \text{ MeV}/c^2$

Planck's constant, $h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s

$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm

Vacuum permittivity, $\varepsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\left(\text{N}\cdot\text{m}^2\right)$

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

Vacuum permeability, $\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A

Magnetic constant, $k' = \mu_0/(4\pi) = 1 \times 10^{-7}$ (T·m)/A

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

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

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

| VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES | | | | | | | |
|---|---|---|---|---|---|---|---|
| $\theta$ | 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.

## 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
$\ell$ = 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
$\mu$ = coefficient of friction
$\theta$ = angle
$\tau$ = torque
$\omega$ = angular speed
$\alpha$ = angular acceleration
$\phi$ = 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
$\ell$ = length
$n$ = number of loops of wire per unit length
$N$ = number of charge carriers per unit volume
$P$ = power
$Q$ = charge
$q$ = point charge
$R$ = resistance
$r$ = radius or distance
$t$ = time
$U$ = potential or stored energy
$V$ = electric potential
$v$ = velocity or speed
$\rho$ = resistivity
$\Phi$ = flux
$\kappa$ = dielectric constant

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

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

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

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

$B_s = \mu_0 n I$

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

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

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

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

## 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

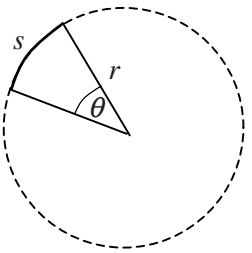
$a^2 + b^2 = c^2$

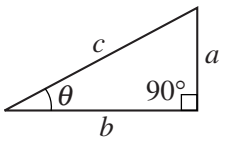
$\sin\theta = \frac{a}{c}$

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

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

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

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

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

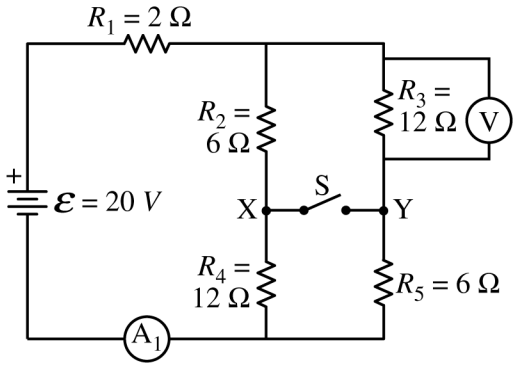
## PHYSICS C: ELECTRICITY AND MAGNETISM

### 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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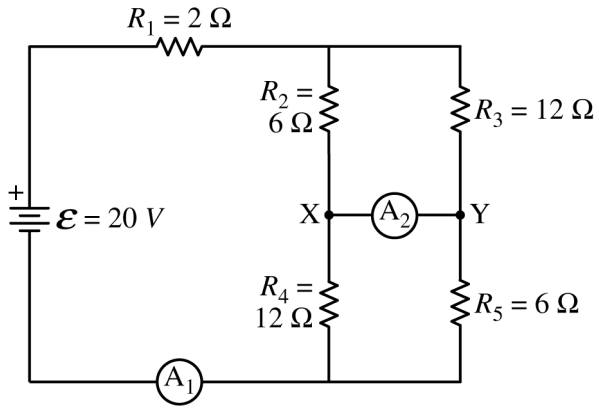
GO ON TO THE NEXT PAGE.

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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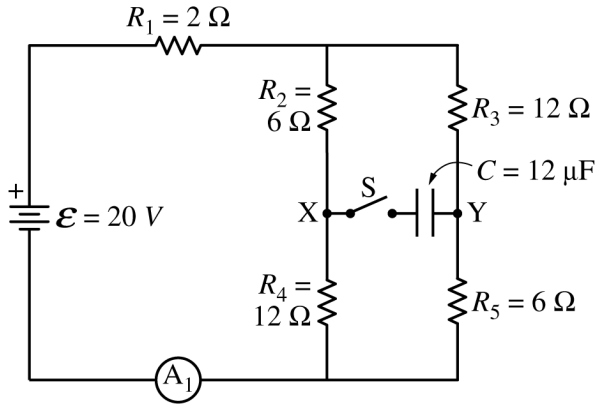


(d) The ammeter $A_2$ is replaced with switch S and capacitor $C = 12\ \mu F$, as shown in the figure above. Switch S is closed.

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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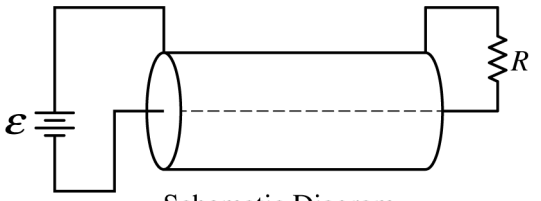
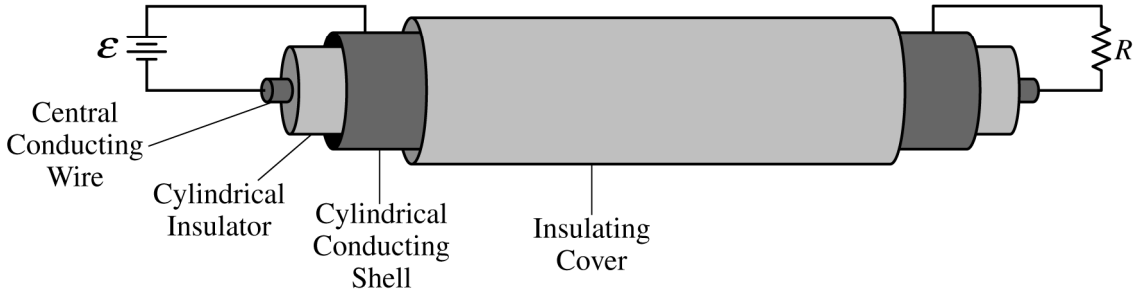
THIS PAGE MAY BE USED FOR SCRATCH WORK.

**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.

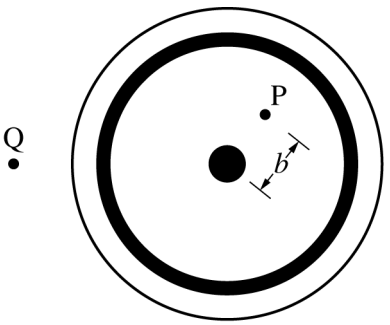



Figure 1

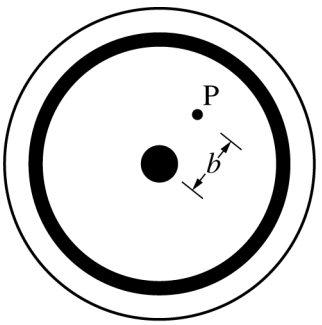



Figure 2

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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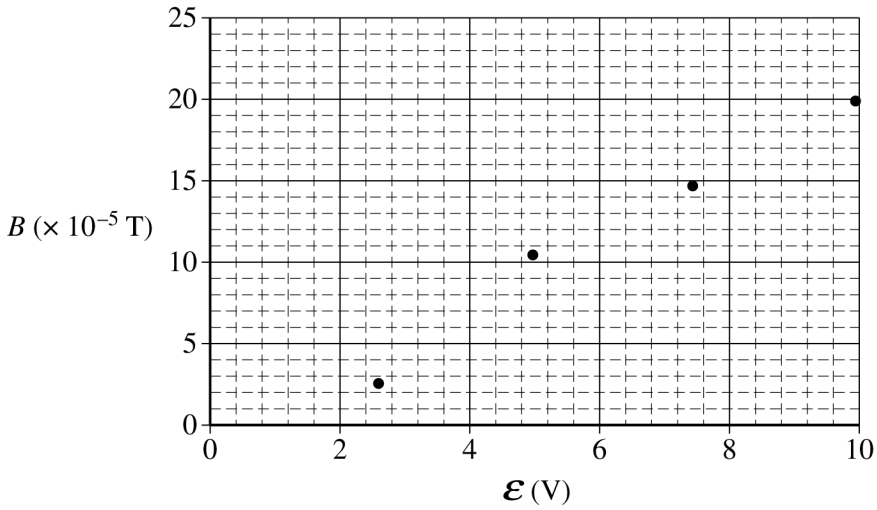
Some physics students conduct an experiment with a coaxial cable in which they connect the cable to a variable power supply and measure the resulting magnetic field strength at point P inside the cylindrical insulator using a magnetic field sensor. Point P is 0.0050 m from the center of the cable. The 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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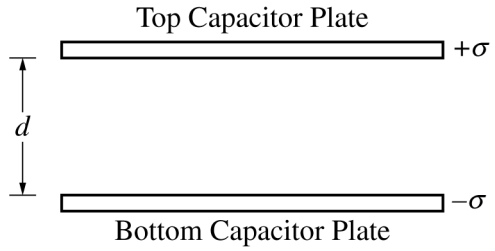
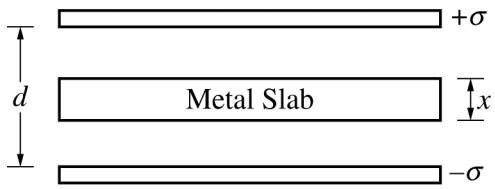



Note: Figure not drawn to scale.

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 $\sigma$, 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 $\sigma$, $d$, $A$, 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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(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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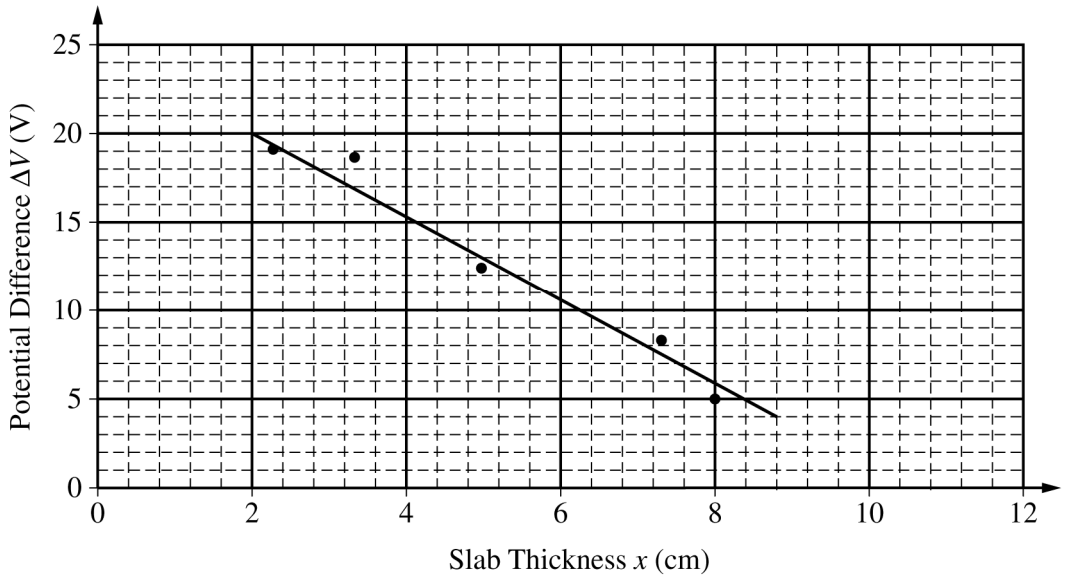
Some physics students conduct an experiment in which they charge the capacitor to the same potential difference, isolate it from the battery, insert the metal slab, and measure the new potential difference across the capacitor. This experiment is repeated with slabs of different thickness. The plot of the potential difference $\Delta V$ 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. $\sigma$, the charge density on the plates

ii. $d$, the distance between the capacitor plates

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THIS PAGE MAY BE USED FOR SCRATCH WORK.

**STOP**

**END OF EXAM**

---

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

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

# 2018年ap物理C电磁学真题答案

## 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

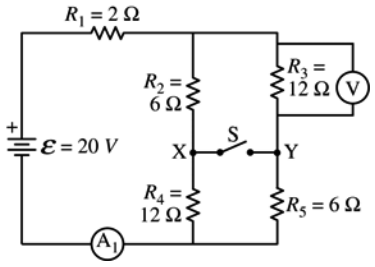
# Free-Response Scoring Guidelines

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

# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2018 SCORING GUIDELINES

## 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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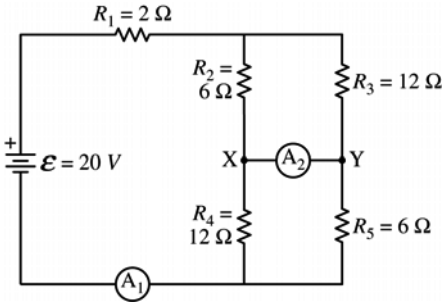
**Question 1 (continued)**

**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"<br>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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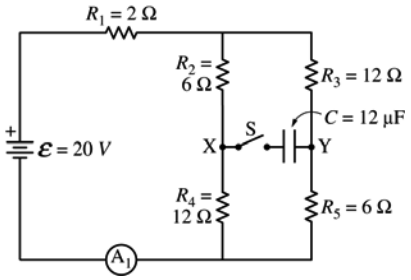
**Question 1 (continued)**

**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.*<br>*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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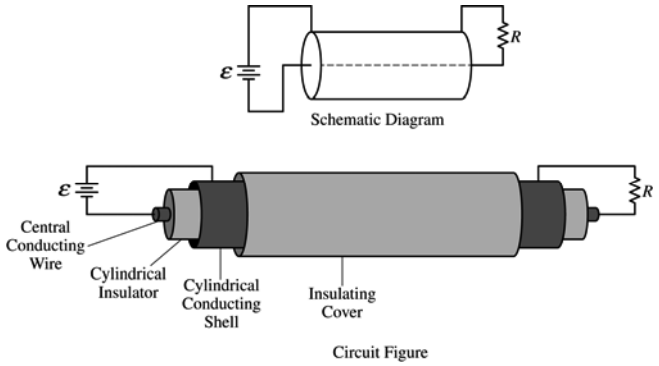
# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2018 SCORING GUIDELINES

## Question 2

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



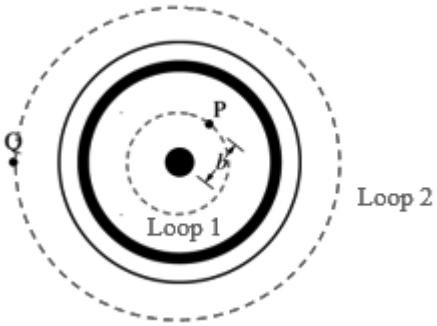

A coaxial cable is composed of a central conducting wire surrounded by a cylindrical insulator, and around that is a conducting cylindrical shell with an insulating cover. A power supply of emf $\mathcal{E}$ is used at one end to connect the two conducting regions, and a resistive load of resistance $R$ 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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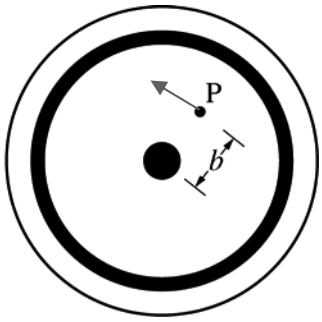
**Question 2 (continued)**

**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 $\varepsilon$ , $R$, $b$, 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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**Question 2 (continued)**

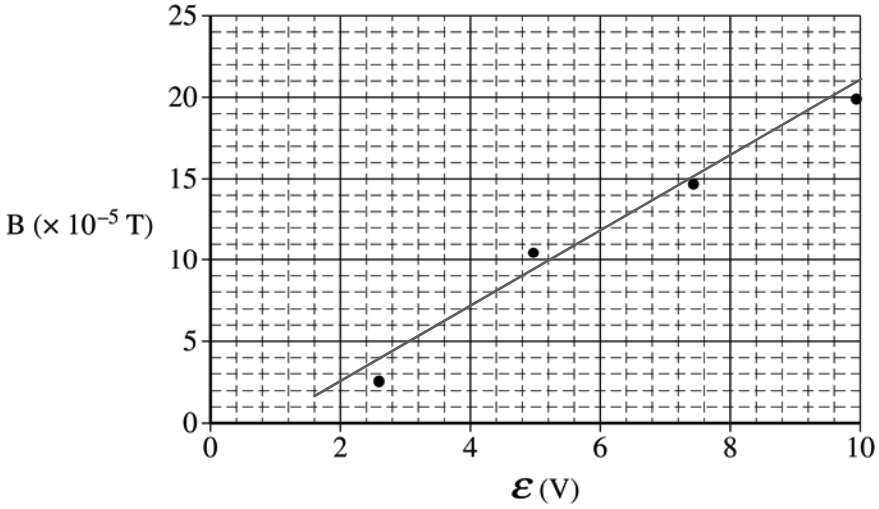
**Distribution of points**

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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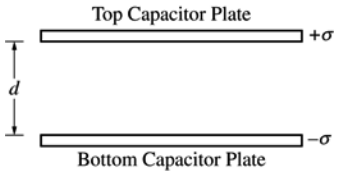
# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2018 SCORING GUIDELINES

## 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 $\sigma$, 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 $\sigma$, $d$, $A$, 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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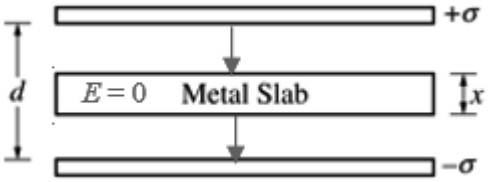
**Question 3 (continued)**

**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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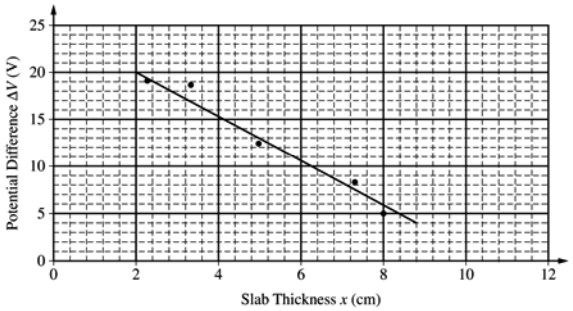
**Question 3 (continued)**

**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 $\Delta V$ 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

$\sigma$, 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 |

# 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 |

From the 2017 Administration

AP CollegeBoard

# Physics C: Electricity and Magnetism

## Practice Exam

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# AP® Physics C: Electricity and Magnetism Exam

## SECTION I: Multiple Choice

**2017**

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

**At a Glance**

**Total Time**
45 minutes
**Number of Questions**
35
**Percent of Total Score**
50%
**Writing Instrument**
Pencil required
**Electronic Device**
Calculator allowed

### Instructions

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

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

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

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

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

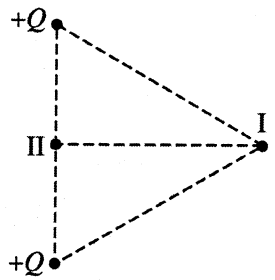
**Form I**
**Form Code 4NBP4-S**

82

## PHYSICS C: ELECTRICITY AND MAGNETISM
## SECTION I
### Time—45 minutes
### 35 Questions

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

**Questions 1-2**




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

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

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

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

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

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

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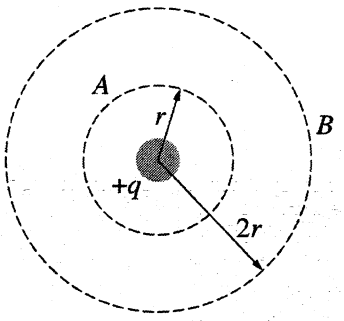
**Questions 3-4**




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

3. The magnitude of the electric flux through $A$ is $\Phi_A$. The magnitude of the electric flux through surface $B$ is $\Phi_B$. The ratio $\Phi_A/\Phi_B$ is

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

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

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

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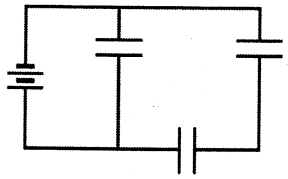
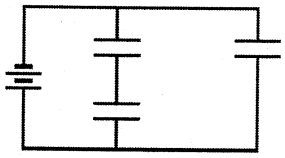
5. Each of the following figures shows three identical capacitors connected to a battery. Which arrangement has the greatest equivalent capacitance?

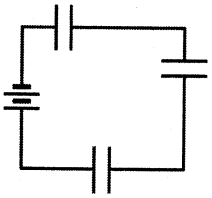
(A)



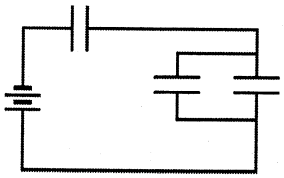
(B)



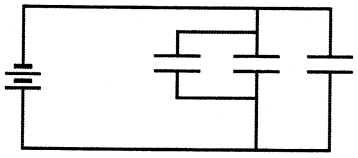
(C)



(D)



(E)



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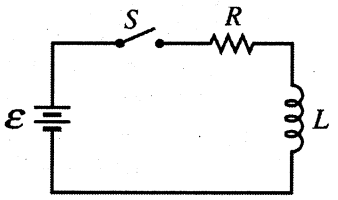
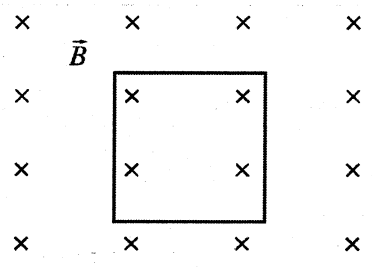
6. A copper wire of length $L$ and diameter $D$ dissipates energy at a rate $P_0$ when the current in the wire is 10 A. A second copper wire of length $L$ has diameter $2D$. What current in the second wire would dissipate energy at a rate $P_0$ ?

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




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

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




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

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

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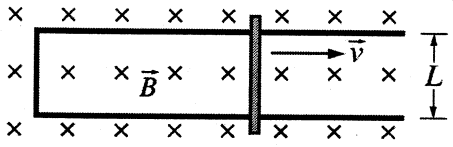


Top View

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

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

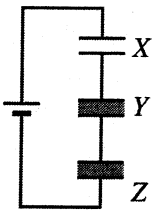


Figure 1

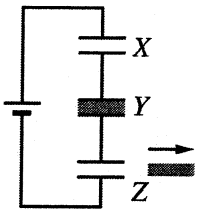


Figure 2

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

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

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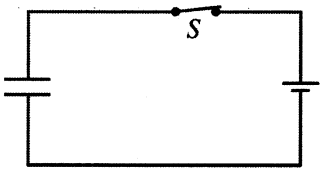
**Questions 11-12**




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

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

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

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

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

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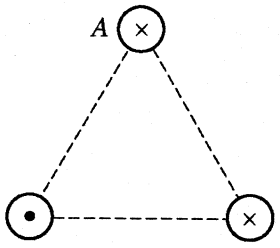


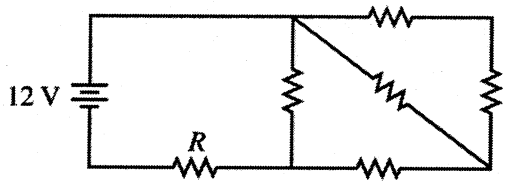

13. Three long wires perpendicular to the page are equidistant from each other, as shown in the cross-sectional view above. Two wires carry current into the page, and the third carries current out of the page. All the currents are equal in magnitude. What is the direction of the net magnetic force on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

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

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

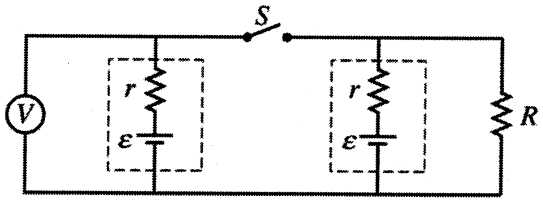
I. The charge of the particle
II. The mass of the particle
III. The velocity of the particle

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




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

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




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

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

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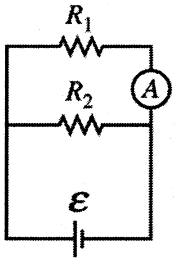
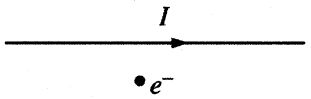



17. In the circuit shown, $R_1 = 6\ \Omega$, $R_2 = 3\ \Omega$, and the emf $\mathcal{E}$ of the battery is 30 V. The reading of the ammeter $A$ is most nearly

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

**Questions 18-19**




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

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

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

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

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

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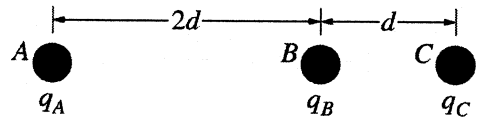
**Questions 20-22**




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

20. The ratio $q_C/q_B$ is

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

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

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

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

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

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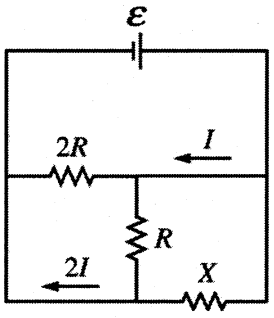
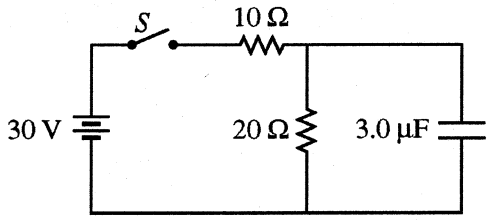



23. Three resistors are connected to an ideal battery, as shown in the figure above. The battery has an emf $\varepsilon$. Two of the resistors have known resistances $R$ and $2R$. The third resistor has unknown resistance $X$. The current in two of the branches is shown. What is the value of the unknown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

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

**Questions 24-25**




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

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

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

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

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

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

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

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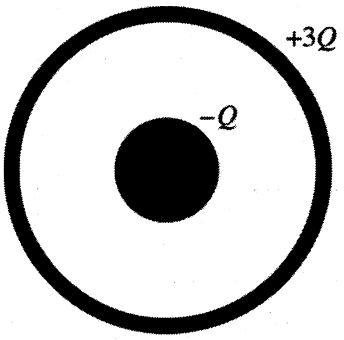
**Questions 27-28**




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

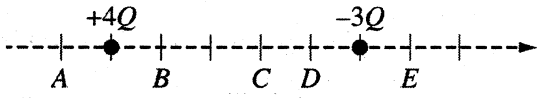
27. What is the net charge on the inner surface of the spherical shell?

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

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

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

**Questions 29-30**




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

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

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

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

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

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

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

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

(A) $I(t) = 0$

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

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

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

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

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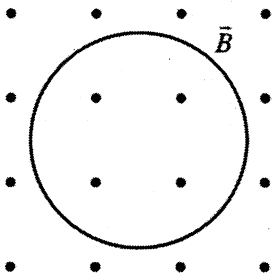



Figure 1

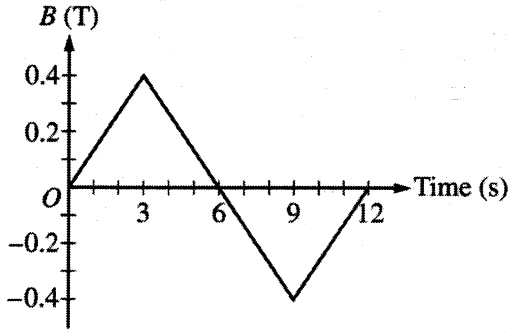
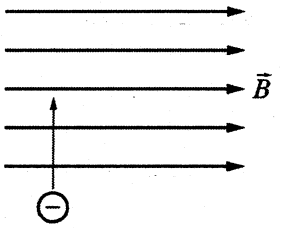



Figure 2

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

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




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

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

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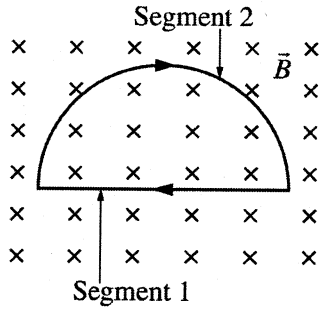


35. A semicircular loop with a clockwise current is placed in a uniform magnetic field that is directed into the page, as shown in the figure above. $\vec{F}_1$ is the net force on segment 1, the straight portion of the loop. $\vec{F}_2$ is the net force on segment 2, the curved portion of the loop.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

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

# STOP

**END OF ELECTRICITY AND MAGNETISM SECTION I**

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

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

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

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

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# AP® Physics C: Electricity and Magnetism Exam

## SECTION II: Free Response

**2017**

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

### At a Glance

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

### IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐
   First letter of your first name ☐
2. Date of birth
   ☐☐ Month ☐☐ Day ☐☐☐☐ Year
3. Six-digit school code
   ☐☐☐☐☐☐
4. Unless I check the box below, I grant the College Board the unlimited right to use, reproduce, and publish my free-response materials, both written and oral, for educational research and instructional purposes. My name and the name of my school will not be used in any way in connection with my free-response materials. I understand that I am free to mark "No" with no effect on my score or its reporting.
   No, I do not grant the College Board these rights. ☐

### Instructions

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

All final numerical answers should include appropriate units. Credit for your work depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should show your work for each part in the space provided after that part. If you need more space, be sure to clearly indicate where you continue your work. Credit will be awarded only for work that is clearly designated as the solution to a specific part of a question. Credit also depends on the quality of your solutions and explanations, so you should show your work.

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

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

**Form I**
**Form Code 4NBP4-S**

**82**

## PHYSICS C: ELECTRICITY AND MAGNETISM

### SECTION II

**Time—45 minutes**

**3 Questions**

**Directions:** Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.

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

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

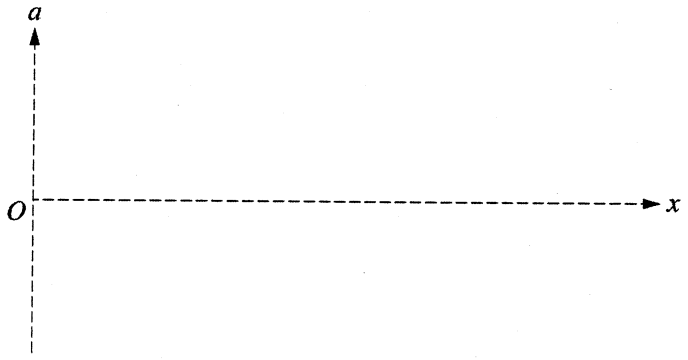
   i. Calculate the magnitude of the work done on the electron by the electric field during this process.

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

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

   (c)

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

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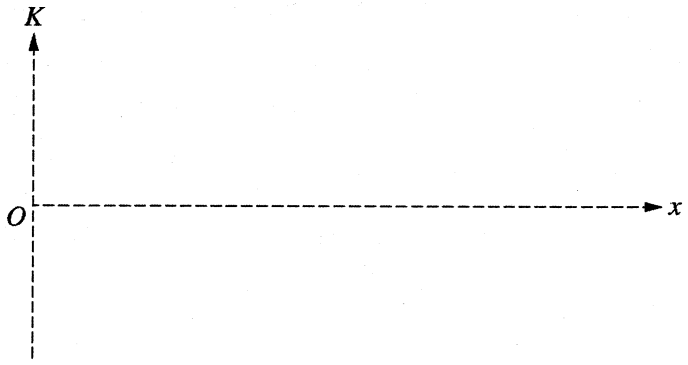
ii. On the axes below, sketch a graph of the kinetic energy of the electron $K$ as a function of position $x$.




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

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

Justify your answer.

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

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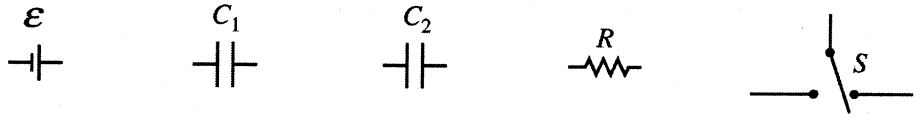
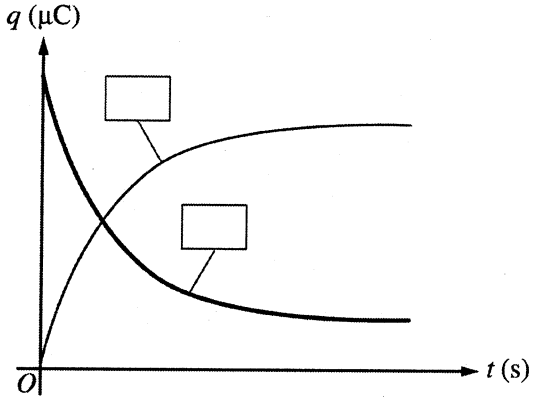
2. A student is to design a circuit using a battery $\mathcal{E}$ with negligible internal resistance, two uncharged capacitors $C_1$ and $C_2$, a resistor $R$, and a switch $S$. The circuit should be set up so that when the switch is in one position, the battery will only charge capacitor $C_1$, and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

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




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

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

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

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

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

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

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

(e)

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

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

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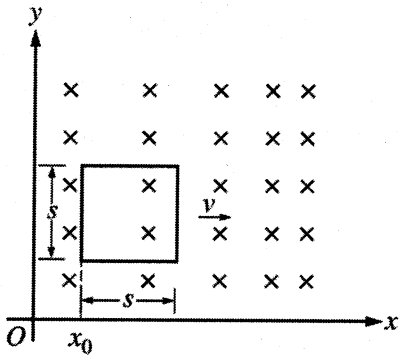


3. A square loop of conducting wire with resistance $R$ and with sides of length $s$ is located in the $xy$-plane. The loop is being pushed at constant speed $v$ by an external force of magnitude $F_{ext}$ in the $+x$-direction through a region with a magnetic field that is directed perpendicular to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

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

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

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

____ Clockwise ____ Counterclockwise ____ Zero

Justify your answer.

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

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

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

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

Justify your answer.

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

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

____ Left _____ Right _____ Top ____ Bottom

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THIS PAGE MAY BE USED FOR SCRATCH WORK.

**STOP**

**END OF EXAM**

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

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

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

Question 1: B
Question 2: A
Question 3: C
Question 4: A
Question 5: E
Question 6: D
Question 7: B
Question 8: E
Question 9: C
Question 10: E
Question 11: A
Question 12: E
Question 13: E
Question 14: E
Question 15: B
Question 16: C
Question 17: C
Question 18: D
Question 19: E
Question 20: A
Question 21: D
Question 22: E
Question 23: C
Question 24: D
Question 25: B
Question 26: E
Question 27: C
Question 28: C
Question 29: C
Question 30: A
Question 31: D
Question 32: D
Question 33: D
Question 34: D
Question 35: A

# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2017 SCORING GUIDELINES

## Question 1

**15 points total**

**Distribution of points**

(a)

i) 2 points

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

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

For a correct answer with units — 1 point

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

ii) 2 points

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

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

For correct substitutions — 1 point

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

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

(b) 2 points

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

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

For a correct answer — 1 point

$$E_x = -4x - 7$$

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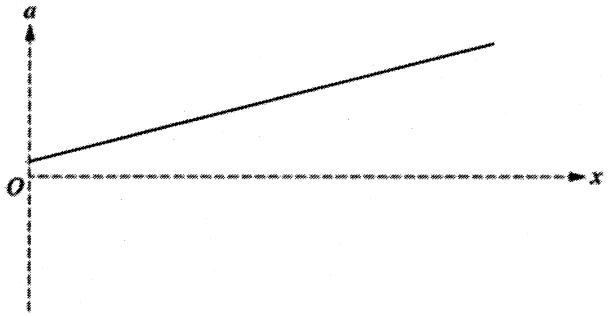
# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2017 SCORING GUIDELINES

## Question 1 (continued)

**Distribution of points**

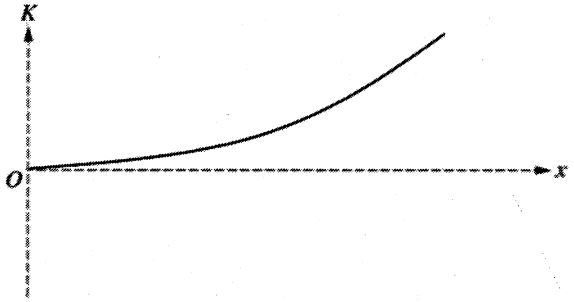
(c)

i) 2 points




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

ii) 2 points




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

(d) 2 points

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

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## Question 1 (continued)

**Distribution of points**

(e) 3 points

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

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

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

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

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

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

For a substitution with the correct limits and signs — 1 point

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

$\Delta V = 800$ V

*Alternate solution* — *Alternate points*

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

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

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

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

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

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

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

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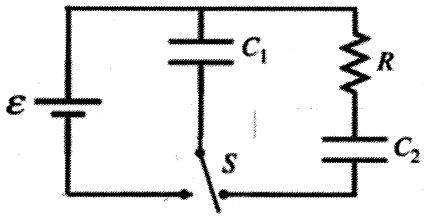
# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2017 SCORING GUIDELINES

## Question 2

**15 points total**

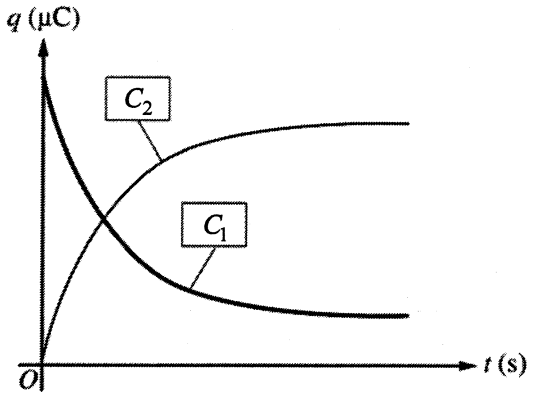
**Distribution of points**

(a) 4 points




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

(b) 1 point




For correctly identifying the two curves — 1 point

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## Question 2 (continued)

**Distribution of points**

(c)

i) 3 points

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

$V_1 = V_2$

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

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

$Q_{tot} = q_1 + q_2$

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

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

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

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

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

$q_1 = 6.0\ \mu C$

$q_2 = 18\ \mu C$

ii) 1 points

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

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

$V_2 = V_1 = 3.0\ V$

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# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2017 SCORING GUIDELINES

## Question 2 (continued)

**Distribution of points**

(d) 3 points

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

$E = \Delta U = U_i - U_f$

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

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

For correctly substituting numerically into the equation above — 1 point

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

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

(e)

i) 2 point

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

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

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

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

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

ii) 1 points

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

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

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

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

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

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# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2017 SCORING GUIDELINES

## Question 3

**15 points total**

**Distribution of points**

(a) 3 points

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

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

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

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

$$\Phi = s\left(\frac{cx_0^2 + 2csx_0 + cs^2}{2} + B_0x_0 + B_0s - \left(\frac{cx_0^2}{2} + B_0x_0\right)\right)$$

For a correct answer — 1 point

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

(b) 3 points

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

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

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

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

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

For dividing by the resistance to calculate the current — 1 point

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

(c) 2 points

Selecting "Counterclockwise"

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

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

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

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# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2017 SCORING GUIDELINES

## Question 3 (continued)

**Distribution of points**

(d) 3 points

For correctly selecting "Left" — 1 point

For indicating that the magnetic forces on the top and bottom parts of the loop are of equal magnitude — 1 point

For indicating that the magnetic force on the right side of the loop is greater than the force on the left side of the loop — 1 point

Example: The magnitude of the magnetic field is the same for the top and bottom of the loop so the forces on the top and bottom of the loop are equal in magnitude and opposite in direction and thus cancel out. The magnitude of the magnetic field is greater at the right side of the loop than at the left side of the loop thus the net force is in the direction of the force on the right side of the loop and this would be toward the left.

(e) 3 points

For indicating that the magnetic force on the loop is the difference in the force on the left and right sides of the loop — 1 point

$F_{ext} = F_R - F_L = B_R IL - B_L IL$

For correctly substituting for the magnetic fields into the above equation — 1 point

$F_{ext} = IL(B_R - B_L) = Is[(c(x+s) + B_0) - (cx + B_0)]$

For correctly substituting current from part (b) — 1 point

$F_{ext} = \left(\frac{vs^2c}{R}\right)s(cs) = \frac{vs^4c^2}{R}$

(f) 1 point

For correctly indicating the correct rankings — 1 point

__3__ Left __1__ Right __2__ Top __2__ Bottom

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# 2017 AP Physics C: Electricity and Magnetism Scoring Worksheet

**Section I: Multiple Choice**

| _____ | × 1.2857 = | _____ |
|---|---|---|
| Number Correct (out of 35) | | Weighted Section I Score (Do not round) |

**Section II: Free Response**

| | | | | |
|---|---|---|---|---|
| Question 1 | _____ (out of 15) | × 1.0000 = | _____ | (Do not round) |
| Question 2 | _____ (out of 15) | × 1.0000 = | _____ | (Do not round) |
| Question 3 | _____ (out of 15) | × 1.0000 = | _____ | (Do not round) |

Sum = _____ Weighted Section II Score (Do not round)

**Composite Score**

| _____ | + | _____ | = | _____ |
|---|---|---|---|---|
| Weighted Section I Score | | Weighted Section II Score | | Composite Score (Round to nearest whole number) |

AP Score Conversion Chart
Physics C: Electricity and Magnetism

| Composite Score Range | AP Score |
|---|---|
| 49-90 | 5 |
| 36-48 | 4 |
| 30-35 | 3 |
| 21-29 | 2 |
| 0-20 | 1 |

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

## Multiple-Choice Questions

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

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

## Free-Response Questions

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

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# AP® Physics C: Electricity and Magnetism Practice Exam

## From the 2016 Administration

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# AP® Physics C: Electricity and Magnetism Exam

## SECTION I: Multiple Choice

**2016**

**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<br>(A) state<br>(B) city<br>(C) country<br>(D) continent<br>(E) village | Ⓐ ● Ⓒ Ⓓ Ⓔ |

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

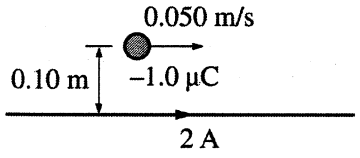
Your total score on the multiple-choice section is based only on the number of questions answered correctly. Points are not deducted for incorrect answers or unanswered questions.

**Form I**
**Form Code 4MBP4-S**

82

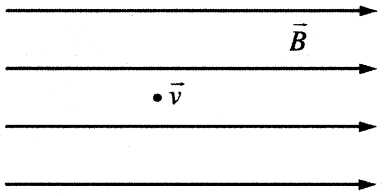
## PHYSICS C: ELECTRICITY AND MAGNETISM
## SECTION I
### Time—45 minutes
### 35 Questions

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




1. A small object of charge −1.0 μC that is 0.10 m above a long, straight wire moves at a speed of 0.050 m/s parallel to the wire, as shown in the figure above. The current in the wire is 2 A. What is the magnitude and direction of the magnetic force on the object?

   (A) $2 \times 10^{-13}$ N, toward the wire
   (B) $2 \times 10^{-13}$ N, away from the wire
   (C) $4\pi \times 10^{-13}$ N, toward the wire
   (D) $4\pi \times 10^{-13}$ N, away from the wire
   (E) 0, direction is undefined




2. An electron travels through a uniform magnetic field $\vec{B}$ directed to the right. The electron's velocity $\vec{v}$ is directed out of the page, as shown in the figure above. The direction of the force on the electron due to the magnetic field at the instant shown is

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

3. Two long parallel wires have currents of $I_1$ and $I_2$ and are a distance $d$ apart. The force per unit length exerted by one wire on the other is $F/L$. The current in each wire is doubled, and the distance between the wires is reduced to $d/2$. The new force per unit length is

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

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**Questions 4-5**

A capacitor is constructed of two large, identical, parallel metal plates separated by a small distance $d$. A battery fully charges the capacitor and is then disconnected.

4. The plate separation is now increased to a distance $2d$. Which of the following correctly describes the change, if any, of the voltage across the capacitor, the electric field between the plates, and the energy stored in the capacitor?

| | Voltage | Electric Field | Energy |
|---|---|---|---|
| (A) | Does not change | Does not change | Does not change |
| (B) | Does not change | Doubles | Does not change |
| (C) | Doubles | Doubles | Does not change |
| (D) | Doubles | Does not change | Doubles |
| (E) | Doubles | Doubles | Doubles |

5. If, instead of separating the plates, the empty space between the plates is filled with a slab of insulating material that has a dielectric constant $K = 2$, which of the following correctly describes the change, if any, of the voltage across the capacitor, the electric field between the plates, and the energy stored in the capacitor?

| | Voltage | Electric Field | Energy |
|---|---|---|---|
| (A) | Halves | Halves | Halves |
| (B) | Halves | Halves | Does not change |
| (C) | Does not change | Does not change | Halves |
| (D) | Does not change | Halves | Halves |
| (E) | Does not change | Does not change | Does not change |

---

6. A capacitor stores energy $U_1$ when it holds charge $Q$. The same capacitor stores energy $U_2$ when it holds charge $16Q$. What is the ratio $U_2/U_1$?

(A) 8
(B) 16
(C) 64
(D) 128
(E) 256

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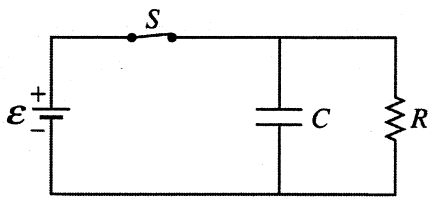
**Questions 7-8**




Switch $S$ in the circuit shown above has been closed for a long time.

7. Which of the following is the correct expression for the current in the resistor?

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

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

(C) $C\mathcal{E}$

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

(E) Zero

8. Suppose that the switch is opened at time $t = 0$. Which of the following combinations of a differential equation and an initial condition can be used to solve for the charge $Q(t)$ on the upper plate of the capacitor as a function of time $t$?

| | Differential Equation | Initial Condition |
|---|---|---|
| (A) | $\frac{Q}{C} - R\frac{dQ}{dt} = 0$ | $Q(0) = C\mathcal{E}$ |
| (B) | $\frac{Q}{C} - R\frac{dQ}{dt} = \mathcal{E}$ | $Q(0) = 0$ |
| (C) | $\frac{Q}{C} + R\frac{dQ}{dt} = \mathcal{E}$ | $Q(0) = C\mathcal{E}$ |
| (D) | $\frac{Q}{C} + R\frac{dQ}{dt} = 0$ | $Q(0) = 0$ |
| (E) | $\frac{Q}{C} + R\frac{dQ}{dt} = 0$ | $Q(0) = C\mathcal{E}$ |

9. A nonconducting sphere of radius $R$ has a uniform volume charge density $\rho$. At the surface of the sphere, the electric field strength is $E$. If a second sphere of radius $2R$ was created of the same material and with the same charge density, what would be the strength of the electric field at the surface of the second sphere?

(A) $E/4$

(B) $E/2$

(C) $E$

(D) $2E$

(E) $4E$

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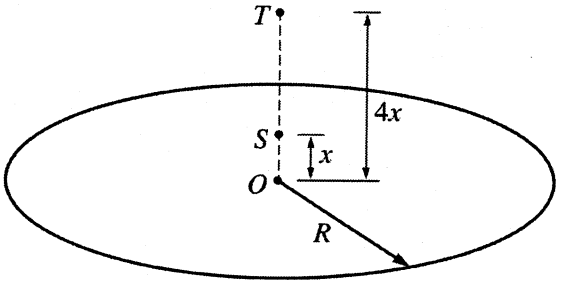
**Questions 10-11**




Note: Figure not drawn to scale.

The figure above shows a thin, circular nonconducting sheet of positive charge uniformly distributed over its area. The radius of the sheet is $R$. Point $O$ is at the center of the sheet. Point $S$ is a distance $x$ from the center of the sheet, and point $T$ is a distance $4x$ from the center of the sheet. Assume $R \gg x$.

10. If the magnitude of the electric field at point $T$ is $E_T$, which of the following best represents the magnitude of the electric field at point $S$?

(A) $E_T/16$

(B) $E_T/4$

(C) $E_T$

(D) $4E_T$

(E) $16E_T$

11. A small sphere of mass $m$ and charge $-q$ is released from rest at point $T$. If the electric potentials at points $S$ and $T$ are $V_S$ and $V_T$, respectively, what is the speed of the sphere when it reaches point $S$? Ignore the effects of gravity.

(A) $\frac{2q}{m}(V_S + V_T)$

(B) $\frac{4q}{m}(V_S + V_T)$

(C) $\sqrt{\frac{q}{2m}(V_S - V_T)}$

(D) $\sqrt{\frac{q}{2m}(V_S + V_T)}$

(E) $\sqrt{\frac{2q}{m}(V_S - V_T)}$

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**Questions 12-13**

| Capacitor | $K$ | $L$ | $M$ | $N$ |
|---|---|---|---|---|
| Plate area | $A$ | $A$ | $2A$ | $2A$ |
| Plate separation | $d$ | $2d$ | $d$ | $2d$ |

The chart above shows the plate area and separation for four different air-filled parallel-plate capacitors: *K*, *L*, *M*, and *N*.

12. Each capacitor is charged such that the same electric field is created between the plates. Which of the following correctly ranks the charge stored on each capacitor?

(A) $(Q_M = Q_N) > (Q_K = Q_L)$
(B) $Q_M > Q_K > Q_N > Q_L$
(C) $(Q_K = Q_M) > (Q_L = Q_N)$
(D) $Q_K = Q_L = Q_M = Q_N$
(E) $Q_M > (Q_K = Q_N) > Q_L$

13. Each capacitor is charged such that the same potential difference exists across the plates. Which of the following correctly ranks the magnitude of electric field between the plates of each capacitor?

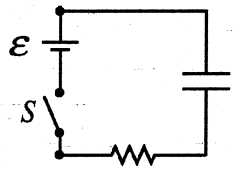
(A) $(E_M = E_N) > (E_K = E_L)$
(B) $E_M > E_K > E_N > E_L$
(C) $(E_K = E_M) > (E_L = E_N)$
(D) $E_K = E_L = E_M = E_N$
(E) $E_L > (E_K = E_N) > E_M$

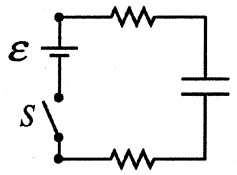
---

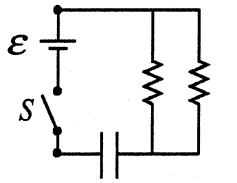
14. A parallel-plate capacitor stores 240 nC when fully charged by the application of a 12 V potential difference across its plates. What is its capacitance?

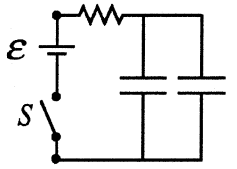
(A) $5.0 \times 10^{-11}$ F
(B) $1.7 \times 10^{-9}$ F
(C) $2.0 \times 10^{-8}$ F
(D) $2.9 \times 10^{-6}$ F
(E) $4.8 \times 10^{-6}$ F

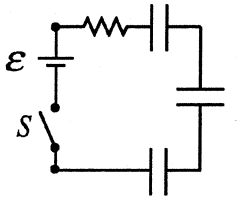
15. Identical resistors and identical uncharged capacitors are connected to identical ideal batteries of emf $\mathcal{E}$ in the circuits shown below. Each circuit has a switch *S* in the open position. In which circuit will the capacitors reach half their maximum charge in the least amount of time when switch *S* is closed?

(A)



(B)



(C)



(D)



(E)
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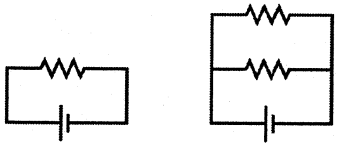
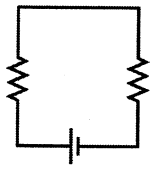


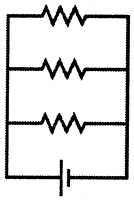
Circuit I



Circuit II



Circuit III



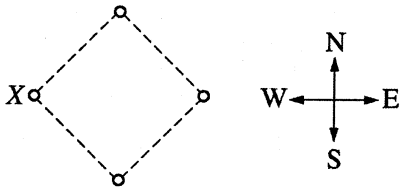
Circuit IV

16. All four circuits shown above contain identical ideal batteries and identical resistors. Which circuits draw the most and least power from the battery?

| | Most Power | Least Power |
|---|---|---|
| (A) | I | II |
| (B) | I | V |
| (C) | II | III |
| (D) | IV | I |
| (E) | IV | III |

17. The current in a 10 Ω resistor is given as a function of time $t$ by the equation $I = I_0 e^{-\alpha t}$, where $I_0 = 4$ A and $\alpha = 2\ \text{s}^{-1}$. What is the total energy dissipated in the resistor from time $t = 0$ until the current becomes zero?

(A) 20 J
(B) 40 J
(C) 80 J
(D) 160 J
(E) 320 J




18. Four conducting wires perpendicular to the plane of the page are at the corners of a square, as shown in cross section in the figure above. The wires carry equal currents in the same direction. What is the direction of the total magnetic force on wire $X$ caused by the other three wires?

(A) To the north
(B) To the south
(C) To the east
(D) To the west
(E) In none of the directions above, since the magnitude of the force is zero

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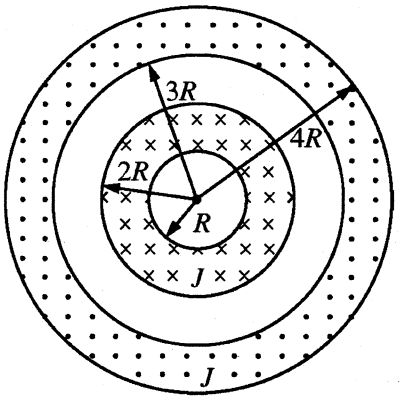
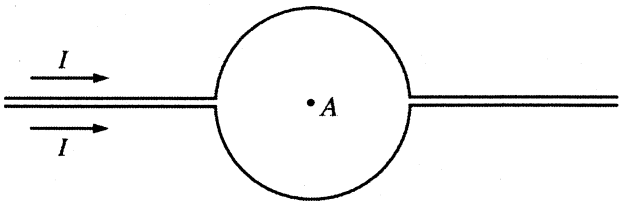



19. Two long, hollow, concentric conducting cylinders carry currents in opposite directions into and out of the plane of the page, as shown in the cross section above. The currents are unequal, but the current density $J$ is the same for both cylinders. In which of the following regions can the net magnetic field be zero at some nonzero finite distance $r$ from the central axis?

(A) $r < R$ only
(B) Both $r < R$ and $R < r < 2R$
(C) Both $r < R$ and $2R < r < 3R$
(D) Both $r < R$ and $3R < r < 4R$
(E) $r > 4R$ only




20. The middle sections of two long, straight wires are each bent into semicircular shapes. The two wires are placed close to each other in a plane as shown above. Point $A$ is the center of the circle formed by the two wires. There is a current $I$ in each wire. Which of the following best represents the direction of the magnetic field, if any, at point $A$ due to the currents?

(A) ↓
(B) ↑
(C) ⊙ (Out of the page)
(D) ⊗ (Into the page)
(E) There is no direction, because the magnetic field is zero.

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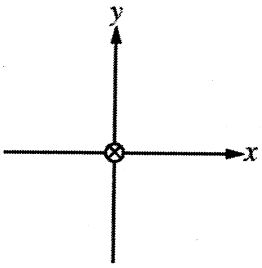
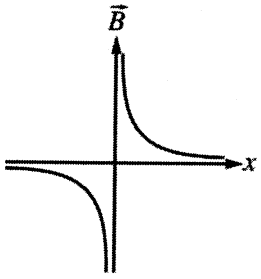
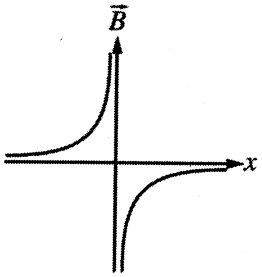
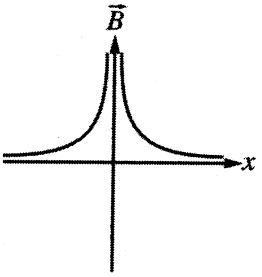
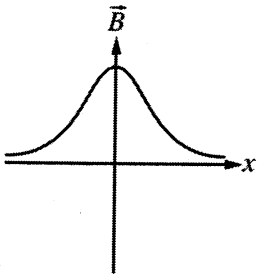


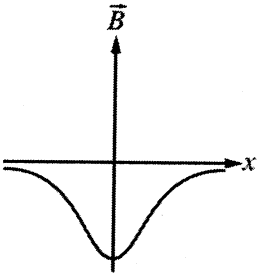

21. A long straight wire is located at the origin of an $xy$-coordinate system and is perpendicular to the $xy$-plane. The wire has a current that is directed into the page, as shown in the figure above. Which of the following graphs best represents the magnetic field $\vec{B}$ due to the current as a function of the position $x$ along the $x$-axis? Assume a positive magnetic field to be directed in the $+y$ direction.

(A)



(B)



(C)



(D)



(E)
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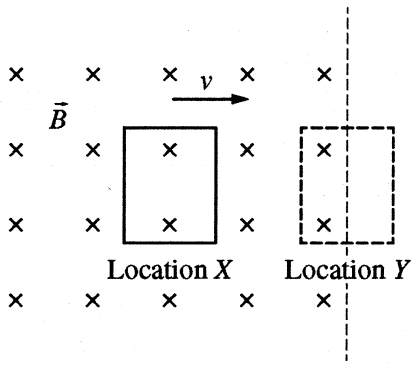


22. A loop of wire at location $X$ is moving toward the right with constant speed $v$ in a region of uniform magnetic field $\vec{B}$, which is perpendicular to the plane of the loop. The magnetic field region ends at the dashed line, as shown in the figure above. Later, the loop is at location $Y$ and exiting the magnetic field with the same constant speed $v$. The process is then repeated with the loop moving at a speed of $2v$. Which of the following best describes the emf in the loop at the two positions shown when the process is repeated at a speed of $2v$ ?

| | Emf at Location $X$ | Emf at Location $Y$ |
|---|---|---|
| (A) | Nonzero and halved | Nonzero and halved |
| (B) | Nonzero and doubled | Nonzero and doubled |
| (C) | Nonzero and doubled | Zero at both speeds |
| (D) | Zero at both speeds | Zero at both speeds |
| (E) | Zero at both speeds | Nonzero and doubled |

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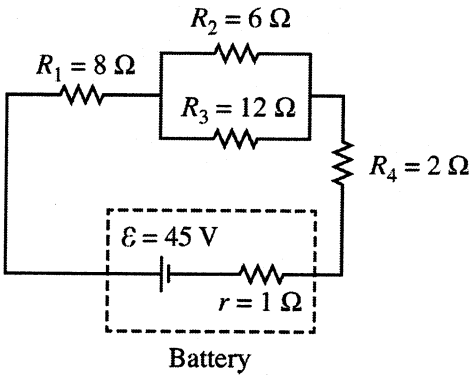
23. A long solenoid has 300 loops. The region inside the solenoid has a uniform magnetic field that is directed parallel to the axis of the solenoid. Each loop has an area $2 \times 10^{-4}$ m$^2$. The magnetic field decreases at a constant rate from 0.5 T to zero. What is the time duration for the change in magnetic field if a potential difference of 10 V is induced between the ends of the solenoid while the field is decreasing?

(A) $1 \times 10^{-5}$ s
(B) $3 \times 10^{-5}$ s
(C) $3 \times 10^{-3}$ s
(D) $1 \times 10^{-2}$ s
(E) $3 \times 10^{-2}$ s




**Questions 24-25**

The circuit represented in the figure above contains four resistors and a battery. The 45 V battery has a 1 Ω internal resistance.

24. Which of the following ranks the absolute values of the potential differences $\Delta V$ across the resistors from highest to lowest?

(A) $\Delta V_3 > \Delta V_1 > \Delta V_2 > \Delta V_4$
(B) $\Delta V_4 > \Delta V_2 > \Delta V_1 > \Delta V_3$
(C) $\Delta V_1 > \Delta V_4 > \Delta V_2 > \Delta V_3$
(D) $\Delta V_1 > (\Delta V_2 = \Delta V_3) > \Delta V_4$
(E) $\Delta V_4 > (\Delta V_2 = \Delta V_3) > \Delta V_1$

25. How much energy is dissipated by the battery's internal resistance in 60 s?

(A) 9 J
(B) 180 J
(C) 540 J
(D) 900 J
(E) 8100 J

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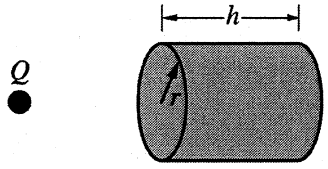



26. A closed cylindrical shell of volume $\pi r^2 h$ is placed close to an object with a charge of $Q$, as shown in the figure above. There are no other charged objects nearby. The electric flux through the closed cylindrical shell is

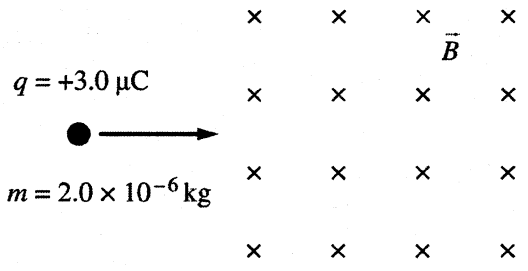
(A) 0
(B) $Q/\varepsilon_0$
(C) $\pi r^2 Q$
(D) $2\pi rhQ$
(E) $2\pi r^2 Q + 2\pi rhQ$

27. The electric field is zero everywhere within a certain region of space. The electric potential everywhere within the region

(A) must be zero
(B) must be uniform
(C) must be positive
(D) must be negative
(E) can be both positive and negative in different parts of the region

28. Two particles with positive charges $q_1$ and $q_2$ are both at rest and are very far apart. How much work would be done by external forces to bring the particles to rest at a distance $d$ apart?

(A) Zero
(B) $\frac{kq_1q_2}{d}$
(C) $-\frac{kq_1q_2}{d}$
(D) $\frac{2kq_1q_2}{d}$
(E) $-\frac{2kq_1q_2}{d}$




29. A small object with a charge of $q = +3.0\ \mu C$ and a mass $m = 2.0 \times 10^{-6}$ kg enters a magnetic field of magnitude $B = 0.20$ T directed into the page, as shown in the figure above. If the speed of the object is 1000 m/s, the object's acceleration at the moment it enters the field is most nearly

(A) zero because the velocity is perpendicular to the magnetic field
(B) 300 $m/s^2$ toward the bottom of the page
(C) 300 $m/s^2$ toward the top of the page
(D) 600 $m/s^2$ toward the bottom of the page
(E) 600 $m/s^2$ toward the top of the page

30. A 0.20 m long wire carries a current of 15 A and lies perpendicular to a magnetic field. The magnetic force on the wire is measured to be 0.060 N. What is the magnitude of the magnetic field?

(A) 0.010 T
(B) 0.020 T
(C) 0.040 T
(D) 0.060 T
(E) 0.080 T

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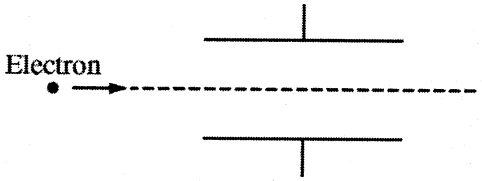
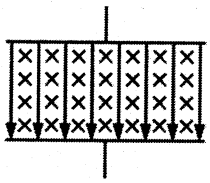
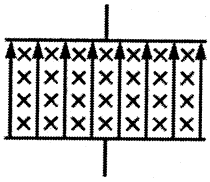



31. Uniform magnetic and electric fields exist between the two oppositely charged parallel plates shown in the figure above. An electron travels horizontally between the plates. Assuming gravitational effects to be negligible, which of the following diagrams shows a combination of electric and magnetic field directions that will allow the electron to travel undeflected?

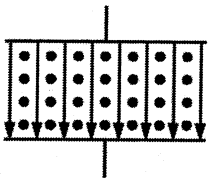
(A)



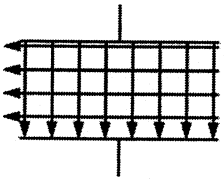
(B)



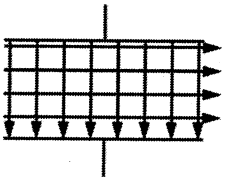
(C)



(D)



(E)



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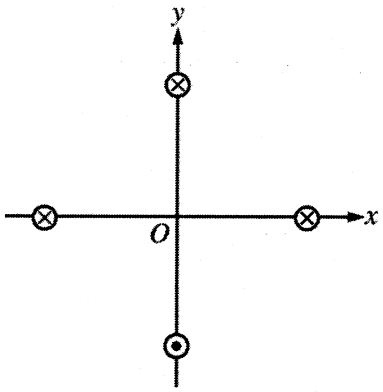


32. Four long, straight wires are perpendicular to the *xy*-plane. Each wire is the same distance from the origin *O*, as shown in the figure above. The wires have equal currents that are in the directions shown. Which of the following best represents the direction of the net magnetic field, if any, at the origin due to the four currents?

(A) 

(B) 

(C) 

(D) 

(E) Undefined because the net field is zero.

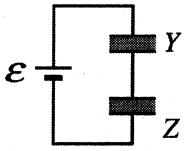


Figure 1

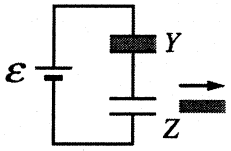


Figure 2

33. Two identical capacitors, Y and Z, are connected in series with an ideal battery, as shown in figure 1 above, and fully charged. Each capacitor has a dielectric slab of dielectric constant $\kappa > 1$ between its plates. If the dielectric slab is removed from capacitor Z, which of the following describes what happens to the voltage across each capacitor?

| | Voltage across Capacitor *Y* | Voltage across Capacitor *Z* |
|---|---|---|
| (A) | Increases | Decreases |
| (B) | Increases | Increases |
| (C) | Remains the same | Remains the same |
| (D) | Decreases | Decreases |
| (E) | Decreases | Increases |

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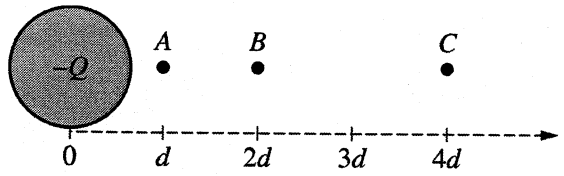
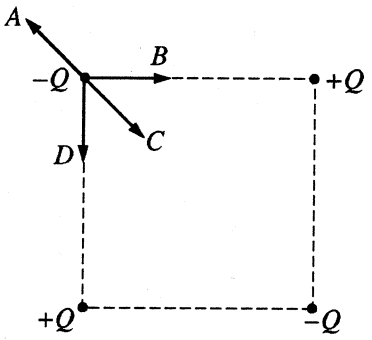



34. A particle of charge $+q$ is released from rest at position $B$, which is a distance $2d$ from the center of a fixed nonconducting sphere that has a charge of $-Q$ distributed uniformly throughout its volume, as shown in the figure above. When the particle reaches position $A$, which is a distance $d$ from the center of the charged sphere, its kinetic energy is $K_0$. The same particle is now released from rest at position $C$, which is a distance $4d$ from the center of the nonconducting sphere. The kinetic energy of the particle when it again reaches position $A$ is

(A) $K_0$
(B) $3K_0/2$
(C) $2K_0$
(D) $5K_0/2$
(E) $3K_0$




35. Four point charges of equal magnitude but different signs are arranged on the corners of a square as shown above. Which of the vectors shown represents the direction of the net force acting on the charge at the upper left-hand corner of the square due to the other charges?

(A) $A$
(B) $B$
(C) $C$
(D) $D$
(E) It has no direction because the force is zero.

# STOP

**END OF ELECTRICITY AND MAGNETISM SECTION I**

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

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# AP® Physics C: Electricity and Magnetism Exam

## SECTION II: Free Response

**2016**

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### 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:

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   First letter of your first name ☐
2. Date of birth
   ☐☐ Month ☐☐ Day ☐☐☐☐ Year
3. Six-digit school code
   ☐☐☐☐☐☐

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### 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 4MBP4-S**
**82**

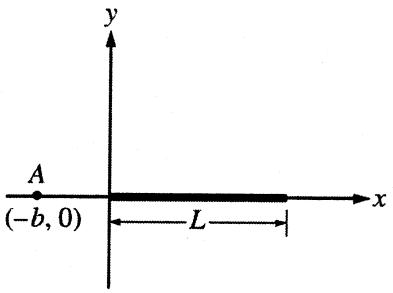
## PHYSICS C: ELECTRICITY AND MAGNETISM

### SECTION II

**Time—45 minutes**

**3 Questions**

**Directions:** Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.




E&M.1.

A rod of length $L$ lies along the $x$-axis with its left end at the origin, as shown in the figure above. The rod has a nonuniform linear charge density $\lambda = \alpha x$, where $\alpha$ is a positive constant.

(a) Determine the units of the constant $\alpha$.

(b) Derive an expression for the total charge on the rod. Express your answer in terms of $\alpha$, $L$, and physical constants, as appropriate.

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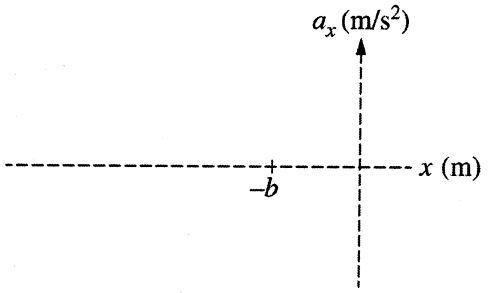
GO ON TO THE NEXT PAGE.

The rod is replaced with one of the same length but with a uniform positive linear charge density $\lambda_0$.

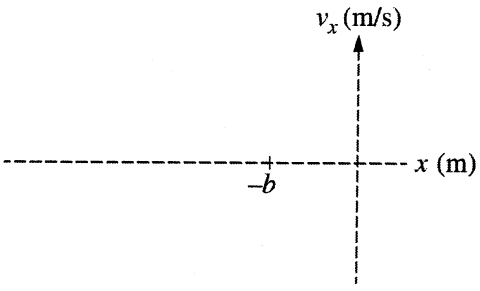
(c) Show that the electric field at point $A$, which is a distance $b$ to the left of the rod, has a magnitude of $E = \dfrac{\lambda_0 L}{4\pi\varepsilon_0 b(b+L)}$.

(d) A proton is placed at point $A$, at position $(-b, 0)$, near the positively charged rod and released from rest.

i. Sketch a graph of the horizontal component of the acceleration of the proton $a_x$ as a function of its position $x$ for the region in which the proton travels after it is released. Sketch any asymptote, but do not indicate its value.




ii. Sketch a graph of the horizontal component of the velocity of the proton $v_x$ as a function of its position $x$ for the region in which the proton travels after it is released. Sketch any asymptote but do not indicate its value.




Question 1 continues on next page.

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iii. Instead of a proton, an alpha particle (a particle with twice the charge and four times the mass of a proton) is now placed at point $A$. Is the magnitude of the initial acceleration of the alpha particle greater than, less than, or equal to the magnitude of the initial acceleration of the proton from part (d)i?

____ Greater than ____ Less than ____ Equal to

(e) Using the equation from part (c), show that the magnitude of the electric field at a point on the $x$-axis very far away from the rod is approximately equal to the electric field due to a point charge of magnitude $Q = \lambda_0 L$ located at the origin.

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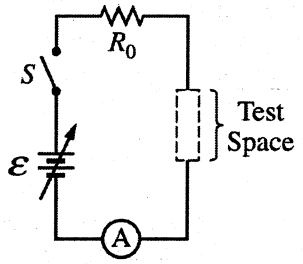


E&M.2.

The circuit above consists of a variable DC power supply, an ammeter A, a switch $S$, and a resistor of unknown resistance $R_0$ connected in series with a test space into which different circuit elements can be placed. In order to determine $R_0$, a wire of negligible resistance is placed in the test space. The power supply is set at various potential differences, and the current in the circuit is measured. The data are shown below.

| $\mathcal{E}$(V) | 2.00 | 4.00 | 6.00 | 8.00 |
|---|---|---|---|---|
| Current (mA) | 0.146 | 0.310 | 0.433 | 0.577 |
| | | | | |
| | | | | |

(a) Indicate below which quantities should be graphed to yield a straight line that has a slope that could be used to calculate a numerical value for the resistance $R_0$.

Horizontal axis: _____

Vertical axis: _____

Use the remaining rows in the table above, as needed, to record any quantities that you indicated that are not given.

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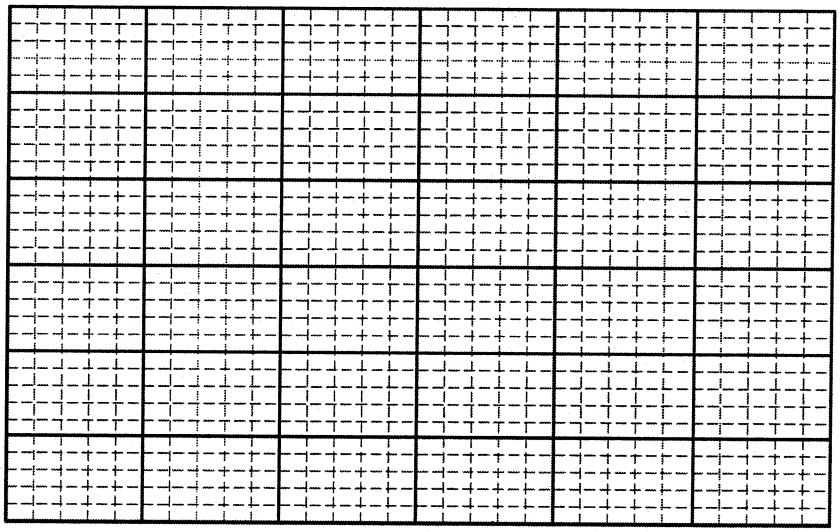
GO ON TO THE NEXT PAGE.

(b) Plot the straight line data points on the graph below. Clearly scale and label all axes, including units, if appropriate. Draw a straight line that best represents the data.



(c) Using your straight line, calculate an experimental value for $R_0$.

Question 2 continues on next page.

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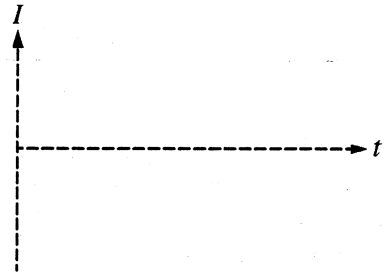
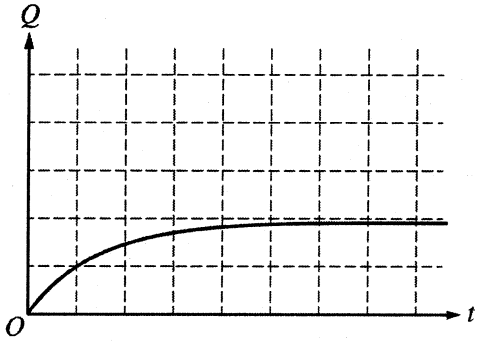
(d) The power supply is set to 4.00 V and an uncharged, air-filled capacitor is placed in the test space. The switch is closed at time $t = 0$, and the capacitor is allowed to fully charge.

i. On the axes shown, sketch the current $I$ through the ammeter as a function of time $t$. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.




ii. It is determined that the time constant is 0.045 s. The capacitor is charged to 4 V. Calculate the energy stored in the capacitor.

iii. The graph below shows the charge $Q$ on the capacitor as a function of time $t$. The capacitor is discharged, and a dielectric with dielectric constant $\kappa = 2$ is inserted between the plates. The same charging procedure is repeated. On the graph below, sketch the curve showing the charge $Q$ on the dielectric-filled capacitor as a function of time $t$.

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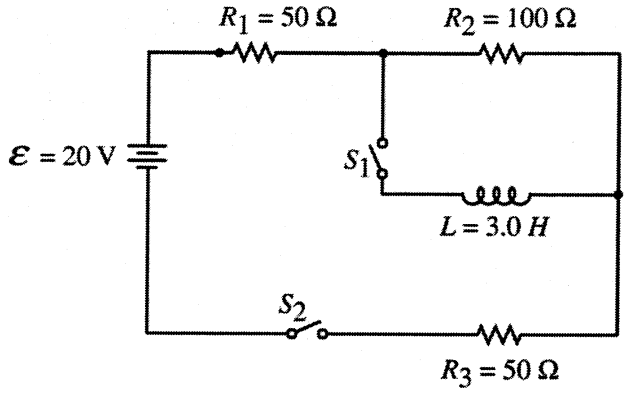


E&M.3.

An ideal battery is connected to three resistors, an ideal inductor, and two switches, as shown in the circuit above. Both switches are initially open. Switch $S_2$ is then closed.

(a) Calculate the voltage across resistor $R_2$.

Switch $S_1$ is then closed.

(b) Calculate the magnitude of the rate of change of the current through the inductor immediately after switch $S_1$ is closed.

(c) At time $t$ after switch $S_1$ is closed, the instantaneous current through resistor $R_2$ is measured to be 0.020 A.

i. Calculate the current through resistor $R_3$ at time $t$.

ii. Calculate the energy stored in the inductor at time $t$.

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GO ON TO THE NEXT PAGE.

After a long time, the currents reach a steady value. Switch $S_2$ is then opened.

(d) Calculate the current through the inductor immediately after switch $S_2$ is opened.

(e) Write, but do NOT solve, a differential equation that can be used to determine the current through resistor $R_2$ at time $t$ after switch $S_2$ is opened.

(f) Using the differential equation from part (e), derive an expression for the current through resistor $R_2$ as a function of time $t$ after switch $S_2$ is opened.

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THIS PAGE MAY BE USED FOR SCRATCH WORK.

**STOP**

**END OF EXAM**

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

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

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

Question 1: B
Question 2: B
Question 3: E
Question 4: D
Question 5: A
Question 6: E
Question 7: A
Question 8: E
Question 9: D
Question 10: C
Question 11: E
Question 12: A
Question 13: C
Question 14: C
Question 15: E
Question 16: E
Question 17: B
Question 18: C
Question 19: D
Question 20: E
Question 21: B
Question 22: E
Question 23: C
Question 24: D
Question 25: C
Question 26: A
Question 27: B
Question 28: B
Question 29: C
Question 30: B
Question 31: A
Question 32: D
Question 33: E
Question 34: B
Question 35: C

# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2016 SCORING GUIDELINES

## Question 1

**15 points total**

**Distribution of points**

(a) 2 points

For correctly solving the given equation for $\alpha$ — 1 point

$\lambda = \alpha x$

$\alpha = \dfrac{\lambda}{x} = \dfrac{Q/L}{x}$

Substituting units into the above equation:

$\alpha = \dfrac{\text{C/m}}{\text{m}}$

For a correct answer — 1 point

$\alpha = \text{C/m}^2$

(b) 2 points

For integrating with the correct limits or constant of integration — 1 point

$$Q = \int \lambda dx = \int_{x=0}^{x=L} \alpha x dx = \left[\frac{1}{2}\alpha x^2\right]_{x=0}^{x=L} = \frac{1}{2}\alpha\left(L^2 - 0\right)$$

For a correct answer — 1 point

$$Q = \frac{1}{2}\alpha L^2$$

(c) 3 points

Using a correct integral expression for Coulomb's law

$$E = \int \frac{1}{4\pi\varepsilon_0}\frac{1}{r^2}\, dq$$

For correctly expressing the charge element in terms of the linear charge density — 1 point

$\lambda_0 = Q/L$ so $dq = \lambda_0 dr$

For correctly substituting into the first equation — 1 point

$$E = \int \frac{1}{4\pi\varepsilon_0}\frac{\lambda_0}{r^2}\, dr$$

For integrating with the correct limits or constant of integration — 1 point

$$E = \frac{\lambda_0}{4\pi\varepsilon_0}\int_{r=b}^{r=b+L} \frac{1}{r^2}\, dr = \frac{\lambda_0}{4\pi\varepsilon_0}\left[-\frac{1}{r}\right]_{r=b}^{r=b+L} = \frac{\lambda_0}{4\pi\varepsilon_0}\left(-\frac{1}{b+L} - \left(-\frac{1}{b}\right)\right)$$

$$E = \frac{\lambda_0}{4\pi\varepsilon_0}\left(\frac{-b+b+L}{b(b+L)}\right)$$

$$E = \frac{1}{4\pi\varepsilon_0}\frac{\lambda_0 L}{b(b+L)}$$

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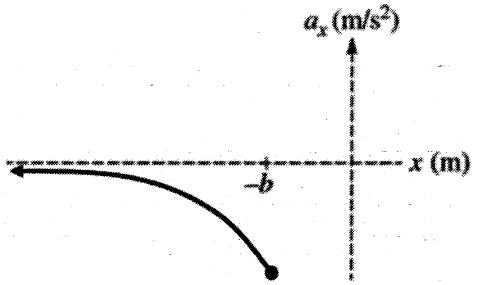
# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2016 SCORING GUIDELINES

## Question 1 (continued)

**Distribution of points**

(d)

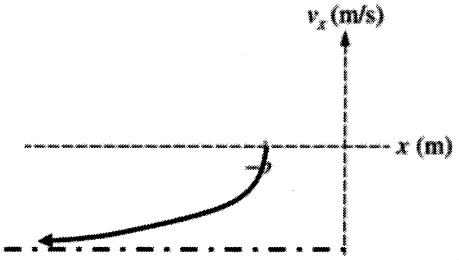
i. 2 points




For a curve starting at negative $b$, extending in the negative $x$ direction, and approaching zero — 1 point

For a curve starting at a finite value that is below the horizontal axis and has the horizontal axis as an asymptote — 1 point

ii. 3 points




For a curve starting at negative $b$ and extending in the negative $x$ direction — 1 point

For a concave up curve that is below the horizontal axis — 1 point

For a curve that has a horizontal non-zero asymptote — 1 point

iii. 1 point

For correctly selecting "Less than" — 1 point

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## Question 1 (continued)

**Distribution of points**

(e) 2 points

For correctly using the assumption that the distance is much greater than the length of the rod — 1 point

$$E = \frac{1}{4\pi\varepsilon_0}\frac{\lambda_0 L}{b(b+L)}$$

Since $b \gg L$, $E = \frac{1}{4\pi\varepsilon_0}\frac{\lambda_0 L}{b^2}$

For correctly substituting $Q$ into the equation above — 1 point

$Q = \lambda_0 L$

$$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{b^2}$$

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# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2016 SCORING GUIDELINES

## Question 2

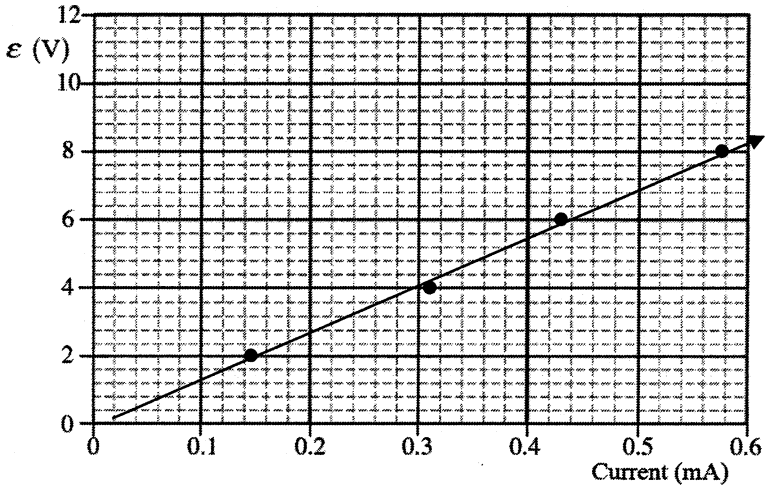
**15 points total** **Distribution of points**

(a) 1 point

For indicating quantities that will yield a straight line that can be used to determine the resistance $R_0$ 1 point

Example:
Horizontal axis: Current
Vertical axis: $\varepsilon$
Note: The axes can be reversed

(b) 4 points




For correctly labeling the axes with appropriate variables and units 1 point
For a correct scale that uses more than half the grid 1 point
For correctly plotting data indicated in part (a) 1 point
For drawing a straight line consistent with the plotted data 1 point

(c) 3 points

For correctly calculating slope using the best-fit straight line and not data points 1 point

$$\text{slope} = \frac{(y_2 - y_1)}{(x_2 - x_1)} = \frac{(8.0 - 2.0)\ \text{V}}{(0.58 - 0.15)\ \text{mA}} = 13.95\ \text{V/mA}$$

Note: Linear regression gives slope = 14.08 V/mA
To get credit for a linear regression, a response must indicate that the value comes from a linear regression from their calculator and the equation of the line must be shown.

For correctly relating $R$ to the slope 1 point
$\varepsilon = IR$ so $R$ = slope

For a correct answer 1 point
$R = 13.95\ \text{k}\Omega$
Note: Linear regression gives $R = 14.08\ \text{k}\Omega$

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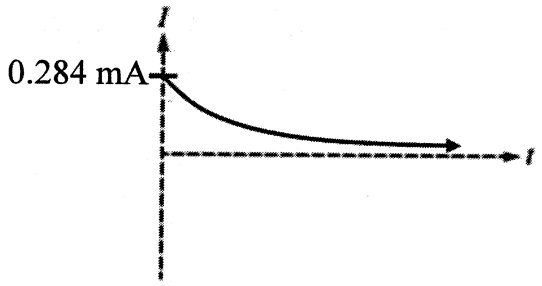
# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2016 SCORING GUIDELINES

## Question 2 (continued)

**Distribution of points**

(d)

i. 3 points




For a concave up curve in the first quadrant — 1 point
For having the horizontal axis as an asymptote — 1 point
For correctly labeling the initial current with units or algebraic expression — 1 point

ii. 2 points

For correctly using the time constant to calculate the capacitance of the capacitor — 1 point

$\tau = RC$

$$C = \frac{\tau}{R} = \frac{(0.045\text{ s})}{(13.95 \times 10^3\ \Omega)} = 3.23 \times 10^{-6}\text{ F}$$

Note: Linear regression gives $C = 3.20 \times 10^{-6}$ F

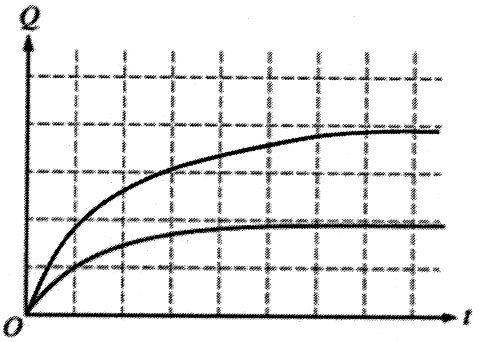
For a correct application of an expression for the energy stored in the capacitor — 1 point

$$U = \frac{1}{2}CV^2 = \left(\frac{1}{2}\right)(3.23 \times 10^{-6}\text{ F})(4\text{ V})^2$$

$U = 2.58 \times 10^{-5}$ J

Note: Linear regression gives $U = 2.56 \times 10^{-5}$ J

iii. 2 points




For a concave down curve starting at the origin and above the original curve — 1 point
For a curve that asymptotes later than the original and at twice the original value. — 1 point

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# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2016 SCORING GUIDELINES

## Question 3

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

(a) 2 points

For correctly using Ohm's law to calculate the current through the resistors — 1 point

$$I = \frac{V}{R} = \frac{(20\text{ V})}{(200\ \Omega)} = 0.10\text{ A}$$

Use Ohm's law to calculate the voltage across $R_2$

$V = IR = (0.10\text{ A})(100\ \Omega)$

For a correct answer — 1 point

$V = 10\text{ V}$

(b) 2 points

For correctly using the equation for the change in current in an inductor — 1 point

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

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

Note: The minus sign may be omitted since the question asks for magnitude

For correctly using the voltage across $R_2$ to calculate the rate of change of current — 1 point

$$\frac{di}{dt} = \frac{(10\text{ V})}{(3.0\text{ H})}$$

$$\frac{di}{dt} = 3.3\text{ A/s}$$

(c)

i. 2 points

For correctly using Ohm's law to calculate the voltage across $R_2$ — 1 point

$V = IR = (0.020\text{ A})(100\ \Omega) = 2.0\text{ V}$

Use Ohm's law to calculate the current through $R_3$

$$I = \frac{\mathcal{E} - V_2}{R_1 + R_3} = \frac{(20\text{ V} - 2.0\text{ V})}{(50\ \Omega + 50\ \Omega)}$$

For a correct answer — 1 point

$I = 0.18\text{ A}$

ii. 2 points

For using the equation to calculate the energy stored in the inductor — 1 point

$$U = \frac{1}{2}LI^2 = \left(\frac{1}{2}\right)(3.0\text{ H})(0.18\text{ A} - 0.020\text{ A})^2$$

For an answer consistent with part (c)i — 1 point

$U = 0.0384\text{ J}$

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## Question 3 (continued)

**Distribution of points**

(d) 2 points

For correctly using Ohm's law to determine the current through the inductor — 1 point

$$I_L = \frac{\mathcal{E}}{R_1 + R_3} = \frac{(20\text{ V})}{(50\ \Omega + 50\ \Omega)}$$

For a correct answer — 1 point

$I_L = 0.20$ A

(e) 2 points

For using the loop rule to relate the inductor emf to the voltage drop across $R_2$ — 1 point

$\mathcal{E}_L = V_{R_2}$

For correctly expressing the loop equation as a differential equation — 1 point

$$-L\frac{di}{dt} = iR_2$$

(f) 3 points

For separation of variables in the differential equation above — 1 point

$$-L\frac{di}{dt} = iR_2$$

$$\frac{1}{i}di = -\frac{R_2}{L}dt$$

For attempting to integrate with the correct limits or the correct constant of integration — 1 point

$$\int_{i_0}^{i(t)} \frac{1}{i}\,di = \int_{t'=0}^{t'=t} -\frac{R_2}{L}\,dt'$$

$$[\ln(i)]_{i_0}^{i(t)} = \left[-\frac{R_2 t'}{L}\right]_{t'=0}^{t'=t}$$

$$\ln\left(\frac{i(t)}{i_0}\right) = -\frac{R_2}{L}(t-0)$$

$$i(t) = i_0 e^{-R_2 t/L} = (0.20\text{ A})e^{-(100\ \Omega)t/(3.0\text{ H})}$$

For a correct answer — 1 point

$i(t) = (0.20\text{ A})e^{-33.3t}$

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# 2016 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 |
|---|---|
| 48-90 | 5 |
| 37-47 | 4 |
| 31-36 | 3 |
| 22-30 | 2 |
| 0-21 | 1 |

# 2016 AP Physics C: Electricity and Magnetism
# Question Descriptors and Performance Data

## Multiple-Choice Questions

| Questions | Topic | Key | % Correct |
|---|---|---|---|
| 1 | Magnetostatics | B | 40 |
| 2 | Magnetostatics | B | 58 |
| 3 | Magnetostatics | E | 41 |
| 4 | Conductors/Cpacitors/Dielectrics | D | 43 |
| 5 | Conductors/Cpacitors/Dielectrics | A | 50 |
| 6 | Conductors/Cpacitors/Dielectrics | E | 34 |
| 7 | Electric Circuits | A | 75 |
| 8 | Electric Circuits | E | 13 |
| 9 | Electrostatics | D | 29 |
| 10 | Electrostatics | C | 19 |
| 11 | Electrostatics | E | 53 |
| 12 | Conductors/Cpacitors/Dielectrics | A | 19 |
| 13 | Conductors/Cpacitors/Dielectrics | C | 45 |
| 14 | Conductors/Cpacitors/Dielectrics | C | 86 |
| 15 | Electric Circuits | E | 29 |
| 16 | Electric Circuits | E | 70 |
| 17 | Electric Circuits | B | 35 |
| 18 | Magnetostatics | C | 39 |
| 19 | Magnetostatics | D | 28 |
| 20 | Magnetostatics | E | 71 |
| 21 | Magnetostatics | B | 42 |
| 22 | Electromagnetism | E | 55 |
| 23 | Electromagnetism | C | 42 |
| 24 | Electric Circuits | D | 67 |
| 25 | Electric Circuits | C | 43 |
| 26 | Electrostatics | A | 47 |
| 27 | Electrostatics | B | 58 |
| 28 | Electrostatics | B | 48 |
| 29 | Magnetostatics | C | 62 |
| 30 | Magnetostatics | B | 70 |
| 31 | Magnetostatics | A | 52 |
| 32 | Magnetostatics | D | 53 |
| 33 | Conductors/Cpacitors/Dielectrics | E | 36 |
| 34 | Electrostatics | B | 32 |
| 35 | Electrostatics | C | 53 |

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# AP® Physics C: Electricity and Magnetism Practice Exam

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# AP® Physics C: Electricity and Magnetism Exam

## SECTION I: Multiple Choice

**2015**

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

### At a Glance

**Total Time**
45 minutes
**Number of Questions**
35
**Percent of Total Score**
50%
**Writing Instrument**
Pencil required
**Electronic Device**
Calculator allowed

### Instructions

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

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

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

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

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

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**Form I**
**Form Code 4KBP6-S**

82

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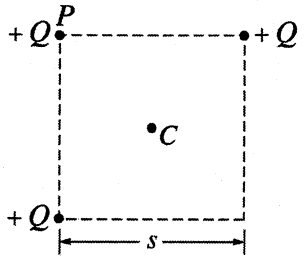
DO NOT seal answer sheet inside

## PHYSICS C: ELECTRICITY AND MAGNETISM
## SECTION I
**Time—45 minutes**
**35 Questions**

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

**Questions 1-2**




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

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

(A) ⟶

(B) ⟵

(C) ↖

(D) ↙

(E) ↘

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

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

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

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

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

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

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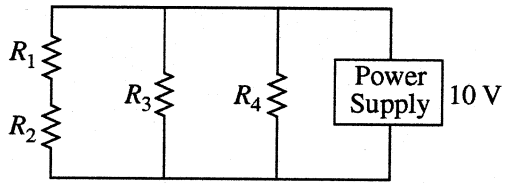
**Questions 3-4**




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

3. What is the equivalent resistance of the network?

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

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

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

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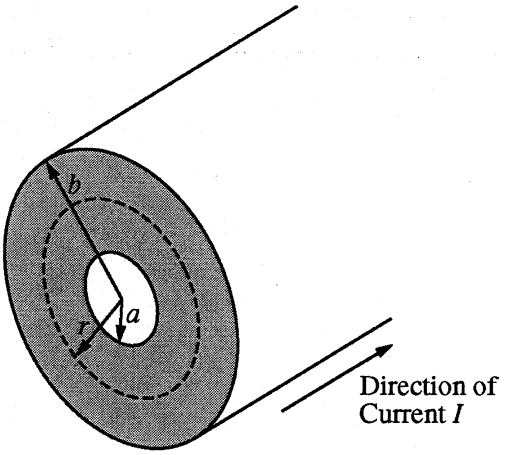
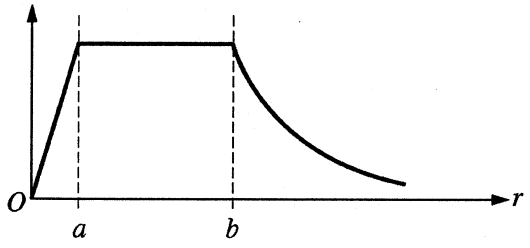



5. A long, cylindrical conductor with inner radius $a$ and outer radius $b$ carries a current $I$ distributed uniformly over its cross section (the shaded region shown above). Which of the following graphs best shows the magnitude of the magnetic field $B$ as a function of the distance $r$ from the axis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

(A)
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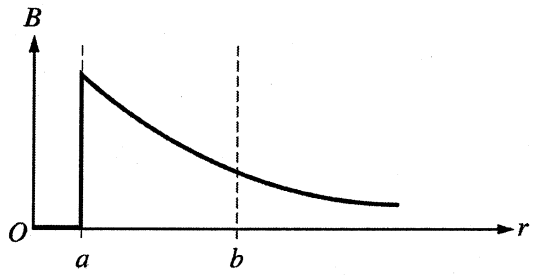


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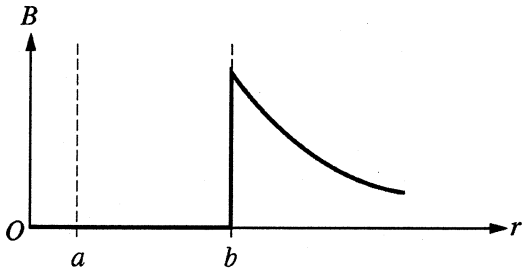


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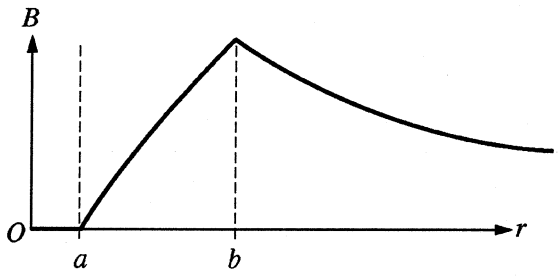


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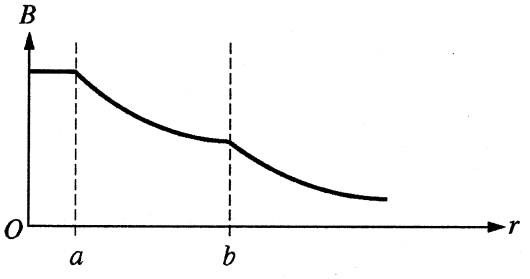


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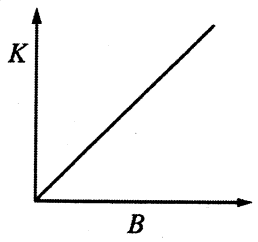
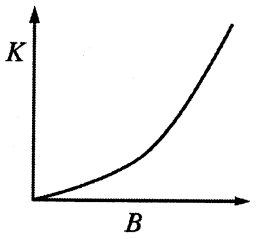
6. A positron (charge $+e$, mass $m_e$) moves in a circular path of radius $R$ due to a uniform magnetic field of strength $B$ applied perpendicular to the plane of the circle. If $B$ is varied, which of the following best represents a graph of the kinetic energy of the positron as a function of $B$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

(A)




(B)

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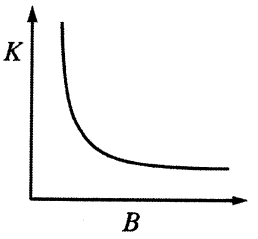


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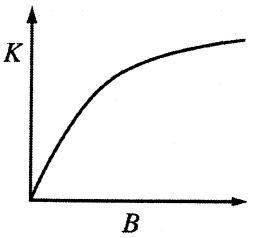
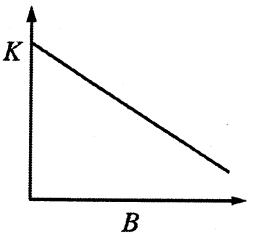



(E)




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

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

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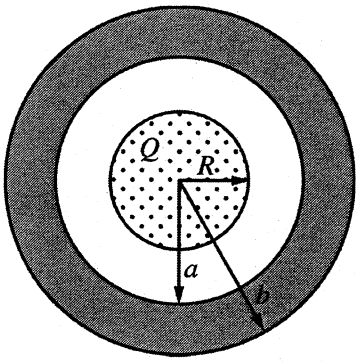
**Questions 8-9**




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

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

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

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

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

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

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

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

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

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

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

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

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

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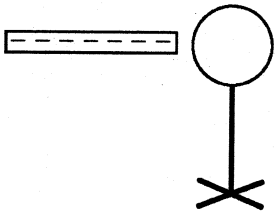
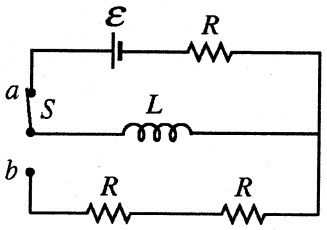


10. A spherical conductor is on an insulating stand, as shown in the figure above. A negatively charged rod is brought close to the sphere but does not touch the sphere. Which of the following describes the resulting charge on the sphere?

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

**Questions 11-13**




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

11. What is the energy stored by the inductor?

(A) Zero

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

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

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

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

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

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

13. The time constant when the switch is in position $a$ is $\tau_0$. How does the time constant when the switch is in position $b$ compare to $\tau_0$?

(A) It is zero.
(B) It is less than $\tau_0$ but greater than zero.
(C) It is equal to $\tau_0$.
(D) It is greater than $\tau_0$ but not infinite.
(E) It is infinite.

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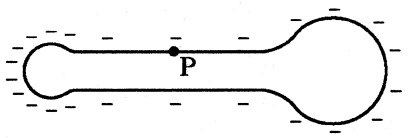
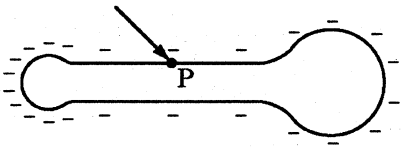
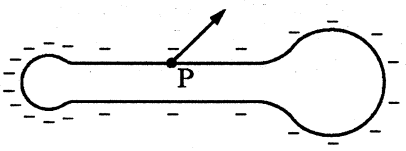
14. If a dielectric is inserted between the plates of a capacitor while the capacitor maintains its connection to a constant voltage source, which of the following is true?

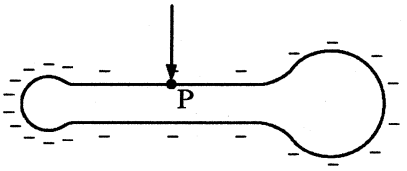
(A) The capacitance of the capacitor is unchanged.
(B) The charge on the capacitor plates increases.
(C) The potential difference across the capacitor increases.
(D) The electric field between the capacitor plates increases.
(E) The electric field between the capacitor plates decreases.

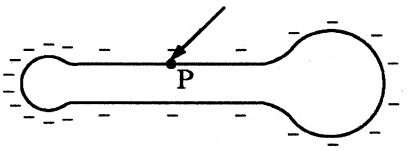


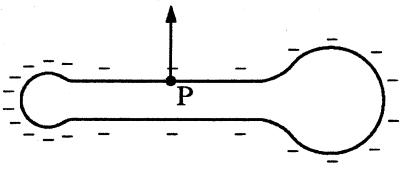

15. The conductor shown above is given a negative charge that spreads over its surface. Which of the following best represents the direction of the electric field at the point P on the cylindrical portion of the conductor?

(A)



(B)



(C)



(D)



(E)
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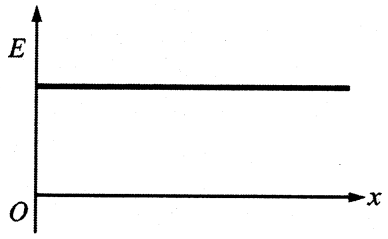
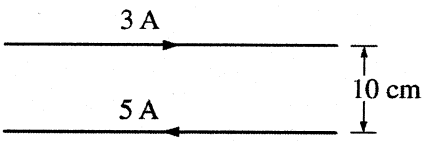



16. The graph above shows the electric field $E$ as a function of $x$, where $x$ is the distance from a given charge arrangement in an $xyz$-coordinate system. Which of the following could be the arrangement?

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

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

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




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

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

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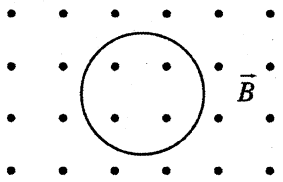
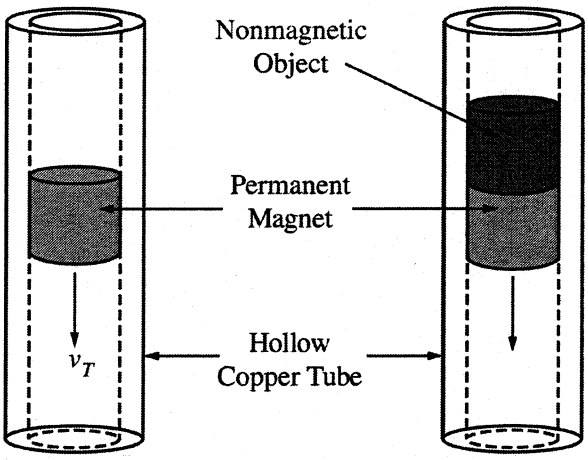



19. A uniform magnetic field $\vec{B}$ is directed out of the page, as represented above. A loop of wire of area $0.8\ \text{m}^2$ is in the plane of the page. At a certain instant, the field has a magnitude of 5.0 T and is decreasing at the rate of 0.5 T/s. The magnitude of the induced emf in the wire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

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




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

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

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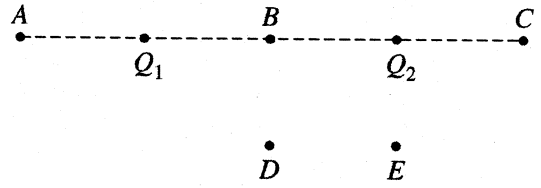
**Questions 21-22**




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

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

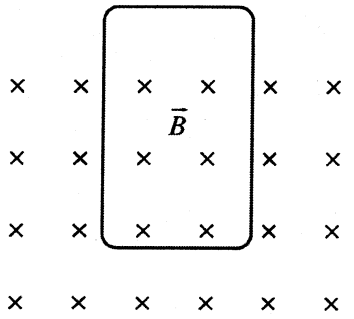
(A) *A*
(B) *B*
(C) *C*
(D) *D*
(E) *E*

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

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

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

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




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

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

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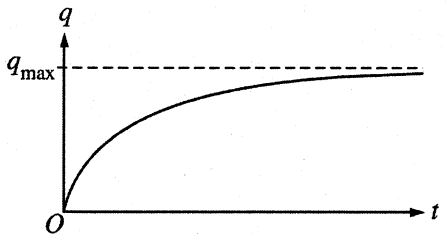
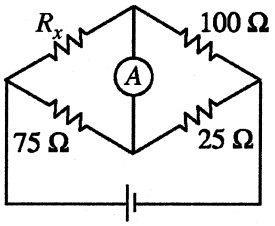



25. A capacitor of capacitance $C$ is connected in series with resistance $R$ and a battery of emf $\mathcal{E}$. The graph above shows the charge $q$ on the capacitor approaching a value $q_{max}$ with increasing time $t$. What is $q_{max}$?

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

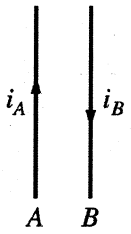
26. A 9 V battery is connected to a 450 Ω load. If the internal resistance of the battery is negligible, how long will it take for 2 C to pass through the load?

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



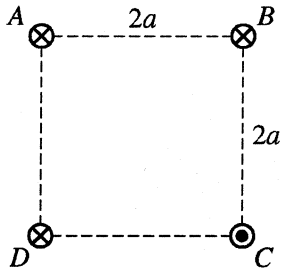

27. In the circuit shown above, the resistances have the values given and there is no current in the ammeter $A$. What is the value of $R_x$?

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




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

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




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

(A) $\frac{\mu_0 I}{\sqrt{2}\pi a}$ toward wire $D$
(B) $\frac{\mu_0 I}{\sqrt{2}\pi a}$ toward wire $B$
(C) $\frac{\mu_0 I}{\sqrt{2}\pi a}$ toward the bottom of the page
(D) $\frac{\mu_0 I}{2\pi a}$ toward wire $D$
(E) $\frac{\mu_0 I}{2\pi a}$ toward wire $B$

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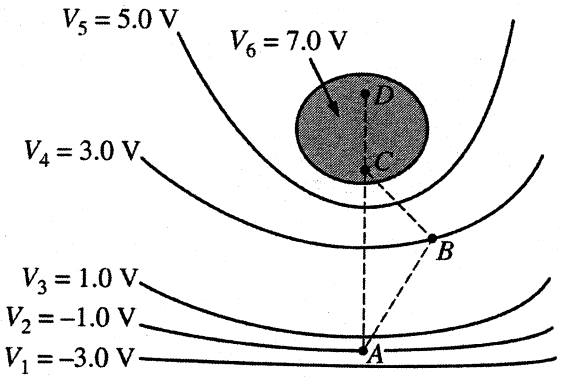
**GO ON TO THE NEXT PAGE.**

**Questions 30-31**




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

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

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

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

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

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

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

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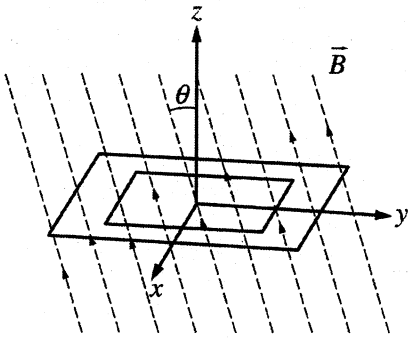


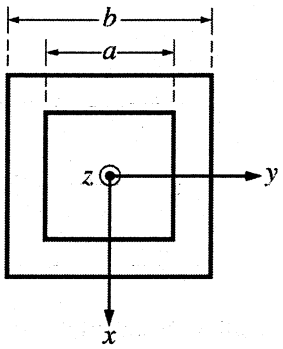


Top View

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

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

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

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

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

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

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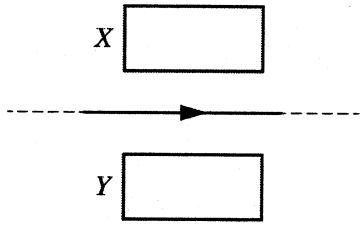
**Questions 34-35**




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

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

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

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

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

# STOP

**END OF ELECTRICITY AND MAGNETISM SECTION I**

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

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

---

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

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

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# AP® Physics C: Electricity and Magnetism Exam

## SECTION II: Free Response

**2015**

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

### At a Glance

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

### IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐
   First letter of your first name ☐
2. Date of birth
   ☐☐ Month ☐☐ Day ☐☐☐☐ Year
3. Six-digit school code
   ☐☐☐☐☐☐
4. Unless I check the box below, I grant the College Board the unlimited right to use, reproduce, and publish my free-response materials, both written and oral, for educational research and instructional purposes. My name and the name of my school will not be used in any way in connection with my free-response materials. I understand that I am free to mark "No" with no effect on my score or its reporting.
   No, I do not grant the College Board these rights. ☐

### Instructions

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

All final numerical answers should include appropriate units. Credit for your work depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should show your work for each part in the space provided after that part. If you need more space, be sure to clearly indicate where you continue your work. Credit will be awarded only for work that is clearly designated as the solution to a specific part of a question. Credit also depends on the quality of your solutions and explanations, so you should show your work.

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

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

**Form I**
**Form Code Z-4FBP2-S**

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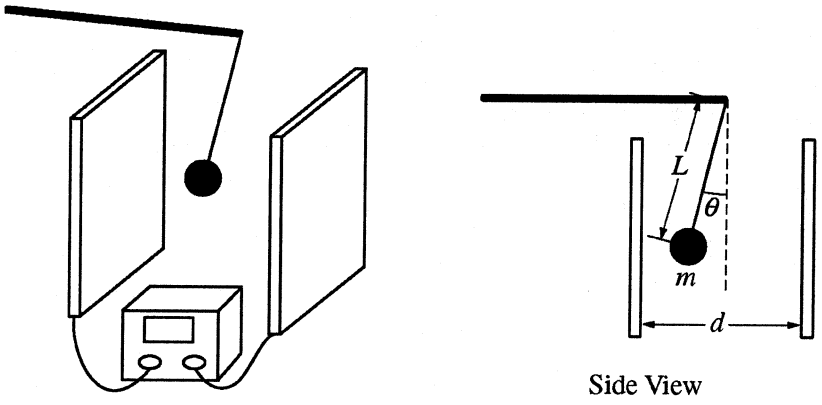
## PHYSICS C: ELECTRICITY AND MAGNETISM

### SECTION II

**Time—45 minutes**

**3 Questions**

**Directions:** Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.

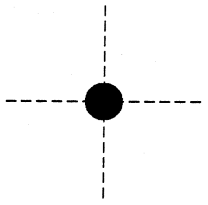



Side View

E&M. 1.

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

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



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GO ON TO THE NEXT PAGE.

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

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

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

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

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

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

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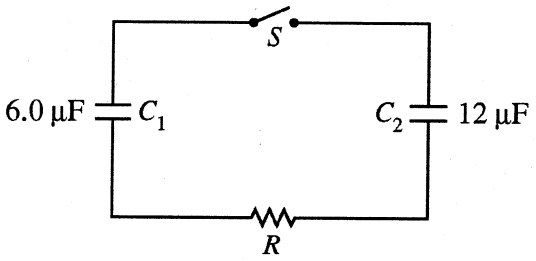


E&M. 2.

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

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

The switch is now closed.

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

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GO ON TO THE NEXT PAGE.

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

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

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

____ Longer ____ The same ____ Shorter

Justify your answer.

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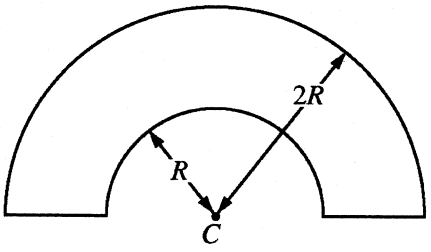


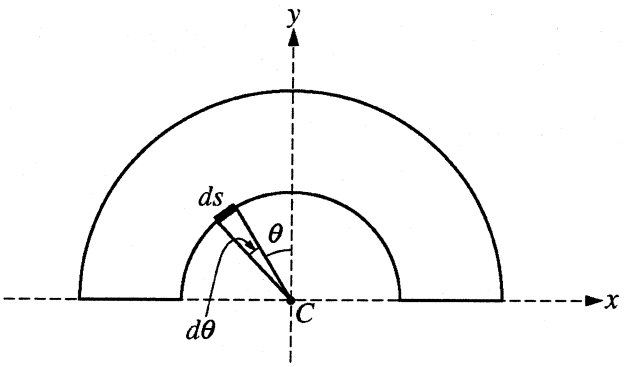


E&M. 3.

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

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

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

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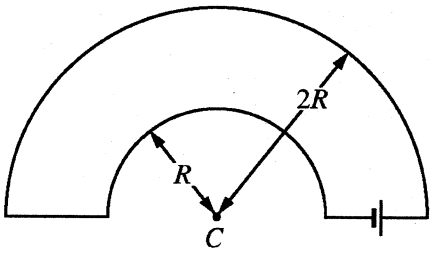
GO ON TO THE NEXT PAGE.

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




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

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

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GO ON TO THE NEXT PAGE.

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

Question 1: E
Question 2: A
Question 3: E
Question 4: C
Question 5: D
Question 6: B
Question 7: D
Question 8: B
Question 9: D
Question 10: C
Question 11: E
Question 12: D
Question 13: B
Question 14: B
Question 15: C
Question 16: E
Question 17: B
Question 18: C
Question 19: A
Question 20: D
Question 21: B
Question 22: C
Question 23: B
Question 24: D
Question 25: E
Question 26: E
Question 27: E
Question 28: D
Question 29: A
Question 30: A
Question 31: E
Question 32: A
Question 33: B
Question 34: A
Question 35: D

# AP® PHYSICS
# 2015 SCORING GUIDELINES

## GENERAL NOTES ABOUT 2015 PHYSICS SCORING GUIDELINES

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

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

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

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

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

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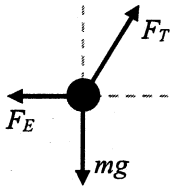
# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2015 SCORING GUIDELINES

## Question 1

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

(a) 3 points




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

(b) 5 points

For using the correct expression for the force due to the electric field — 1 point
$F = qE$

For relating the voltage and the electric field between parallel plates — 1 point
$V = Ed$

For indicating that the ball is in equilibrium — 1 point
$\Sigma \vec{F} = 0$

For a set of equations that leads to an expression for charge $q$ — 1 point
$\Sigma F_x = T\sin\theta - qV/d = 0$
$\Sigma F_y = T\cos\theta - mg = 0$

For a correct expression for $q$ — 1 point
$q = \frac{mgd\tan\theta}{V}$

(c)

i. 1 point

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

ii. 1 point

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

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# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2015 SCORING GUIDELINES

## Question 1 (continued)

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

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# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2015 SCORING GUIDELINES

## Question 2

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

(a) 2 points

For substituting values into the equation for the charge on a capacitor — 1 point
$Q = C_1V = (6\ \mu\text{F})(30\ \text{V})$
For the correct answer — 1 point
$Q = 180\ \mu\text{C} = 1.8 \times 10^{-4}\ \text{C}$

(b) 4 points

For using the loop rule and including the two capacitors and a resistor — 1 point
$V_1 - V_2 - V_R = 0$
For correctly substituting the potential difference across each capacitor — 1 point
$\frac{q_1}{C_1} - \frac{q_2}{C_2} - iR = 0$
For correctly using conservation of charge to eliminate the charge on one of the capacitors from the equation — 1 point
$\frac{Q - q_2}{C_1} - \frac{q_2}{C_2} - iR = 0$
For expressing the current as the derivative of the charge — 1 point
$\frac{Q - q_2}{C_1} - \frac{q_2}{C_2} = \frac{dq_2}{dt}R \quad \Rightarrow \quad \frac{Q}{RC_1} - \frac{q_2}{R}\left(\frac{1}{C_1} + \frac{1}{C_2}\right) = \frac{dq_2}{dt}$

(c) 3 points

For using conservation of charge — 1 point
$Q_1 + Q_2 = 180\ \mu\text{C}$
For recognizing that the potential difference is the same across both capacitors after equilibrium is reached — 1 point
$V = \frac{Q_1}{C_1} = \frac{Q_2}{C_2}$
Combining the equations above and solving
$\frac{180\ \mu\text{C} - Q_2}{6\ \mu\text{F}} = \frac{Q_2}{12\ \mu\text{F}}$
$2160\ \mu\text{C} - 12Q_2 = 6Q_2$
For a correct answer for the charge on each capacitor — 1 point
$Q_1 = 60\ \mu\text{C}$
$Q_2 = 120\ \mu\text{C}$

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# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2015 SCORING GUIDELINES

## Question 2 (continued)

**Distribution of points**

(d) 3 points

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

$\Delta U = U_f - U_i$

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

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

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

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

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

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

(e) 2 points

For correctly selecting "Longer" — 1 point

For a correct justification — 1 point

Units 1 point

For correct units on all numerical answers — 1 point

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# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2015 SCORING GUIDELINES

## Question 3

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

(a) 4 points

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

$dE_y = dE\cos\theta$

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

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

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

For expressing the charge element $dq$ in terms of $\lambda$, $R$, and $\theta$ — 1 point

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

For a correct substitution using the equations above — 1 point

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

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

(b) 5 points

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

$\Sigma E_x = 0$

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

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

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

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

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

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

For a correct answer — 1 point

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

(c) 2 points

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

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

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# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2015 SCORING GUIDELINES

## Question 3 (continued)

**Distribution of points**

(d) 4 points

For using the law of Biot-Savart — 1 point

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

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

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

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

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

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

For a correct answer — 1 point

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

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# 2015 AP Physics C: Electricity and Magnetism Scoring Worksheet

**Section I: Multiple Choice**

| | | | |
|---|---|---|---|
| _____ | × 1.2857 = | _____ |
| Number Correct (out of 35) | | Weighted Section I Score (Do not round) |

**Section II: Free Response**

| | | | |
|---|---|---|---|
| Question 1 | _____ (out of 15) | × 1.0000 = | _____ (Do not round) |
| Question 2 | _____ (out of 15) | × 1.0000 = | _____ (Do not round) |
| Question 3 | _____ (out of 15) | × 1.0000 = | _____ (Do not round) |

Sum = _____
Weighted Section II Score (Do not round)

**Composite Score**

| | | | | |
|---|---|---|---|---|
| _____ | + | _____ | = | _____ |
| Weighted Section I Score | | Weighted Section II Score | | Composite Score (Round to nearest whole number) |

AP Score Conversion Chart
Physics C: Electricity and Magnetism

| Composite Score Range | AP Score |
|---|---|
| 47-90 | 5 |
| 34-46 | 4 |
| 29-33 | 3 |
| 20-28 | 2 |
| 0-19 | 1 |

CollegeBoard

# AP® Physics C: Electricity and Magnetism Practice Exam

## From the 2014 Administration

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# AP® Physics C: Electricity and Magnetism Exam

## SECTION I: Multiple Choice

**2014**

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

**At a Glance**

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

### Instructions

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

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

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

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

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

PLACE SEAL HERE

**Form I**
**Form Code 4JBP6-S**

82

**PLACE SEAL HERE**
DO NOT seal answer sheet inside

## PHYSICS C: ELECTRICITY AND MAGNETISM

### SECTION I

**Time—45 minutes**

**35 Questions**

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

1. Which of the following Gaussian surfaces would be the simplest to use to determine the electric field intensity near a long, straight, charged wire?
   (A) A cylinder whose axis coincides with the wire
   (B) A cylinder whose axis is perpendicular to the wire and passes through the wire
   (C) A sphere with the wire through its center
   (D) A cube with the wire passing through the centers of opposite faces
   (E) A cube with the wire along a diagonal

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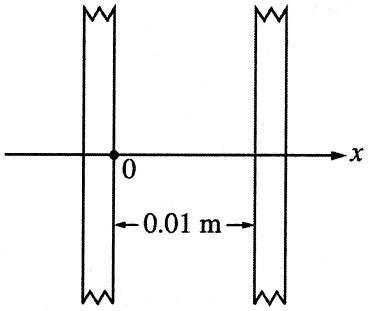
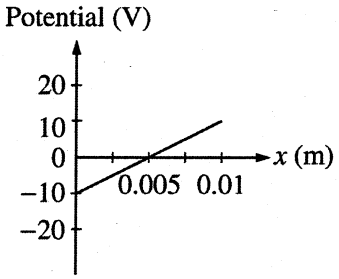
**Questions 2-4**




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

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

   (A) −20 μJ
   (B) −10 μJ
   (C) Zero
   (D) 10 μJ
   (E) 20 μJ

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

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

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

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

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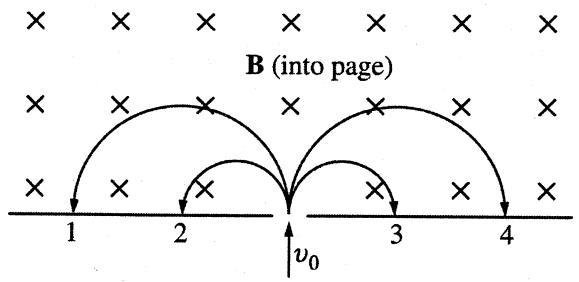
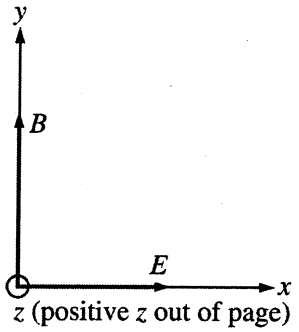



5. Two particles with the same speed $v_0$ enter a region of uniform magnetic field **B** directed into the page and are initially traveling perpendicular to **B**, as shown above. Particle $Y$ has charge $-Q$ and mass $M$; particle $Z$ has charge $+Q$ and mass $2M$. Which of the following pairs of paths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

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

**Questions 6-7**




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

6. The velocity of the particle is in which direction?
   (A) $+y$
   (B) $+x$
   (C) $-x$
   (D) $+z$
   (E) $-z$

7. The magnetic field strength $B$ is equal to
   (A) $E$
   (B) $Ev$
   (C) $\frac{E}{v}$
   (D) $\frac{v}{E}$
   (E) $Ev^2$

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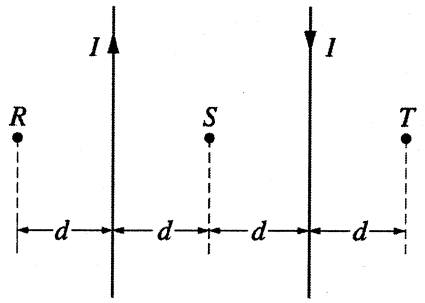


8. Two long, straight, parallel wires in the plane of the page carry equal currents $I$ in opposite directions, as shown above. What are the directions of the resultant magnetic field **B**, if any, at each of the points $R$, $S$, and $T$?

| | $R$ | $S$ | $T$ |
|---|---|---|---|
| (A) | Out of the page | Into the page | Out of the page |
| (B) | Out of the page | None, **B** = 0 | Out of the page |
| (C) | Out of the page | None, **B** = 0 | Into the page |
| (D) | Into the page | None, **B** = 0 | Out of the page |
| (E) | Into the page | Out of the page | Into the page |

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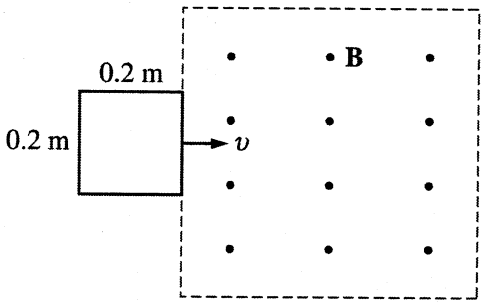
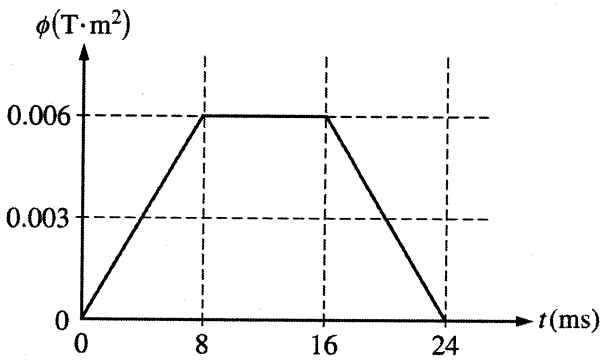
**Questions 9-10**




Note: Figure at left above not drawn to scale.

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

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

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

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

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

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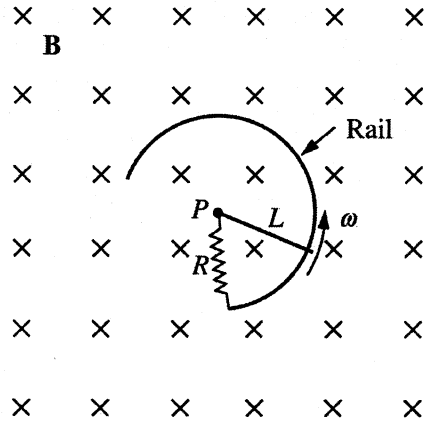
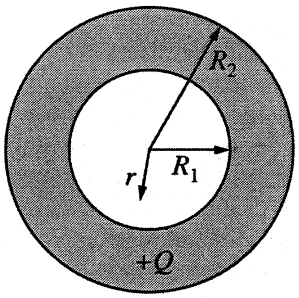



11. A conducting rod of length $L$ is pivoted at point $P$. The other end slides with negligible friction on a conducting rail in the shape of a circular arc. The plane of the rail and rod is perpendicular to a uniform magnetic field of magnitude $B$ directed into the page, as shown in the figure above.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

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

**Questions 12-13**




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

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

(A) zero

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

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

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

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

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

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

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

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

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

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

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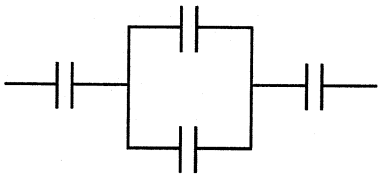
14. The maximum charge a capacitor can store on one plate is limited by which of the following?

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



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

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

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

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

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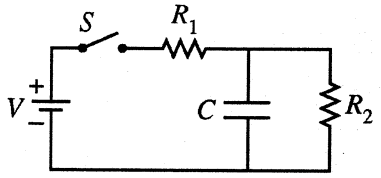
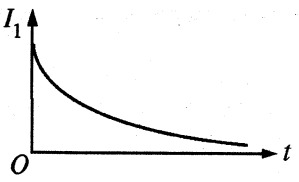
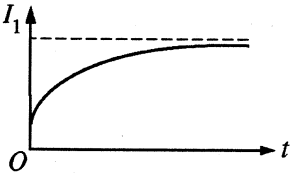
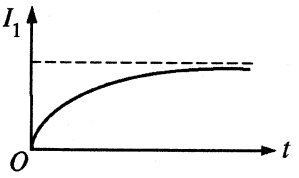
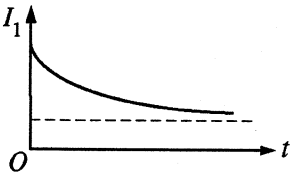


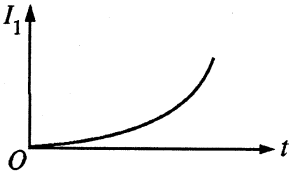

17. Capacitor $C$ and resistors $R_1$ and $R_2$ are connected to a battery as illustrated above. The capacitor is initially uncharged. The battery supplies constant voltage $V$ after the switch $S$ is closed at time $t = 0$. Which of the following graphs best represents the current $I_1$ through the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

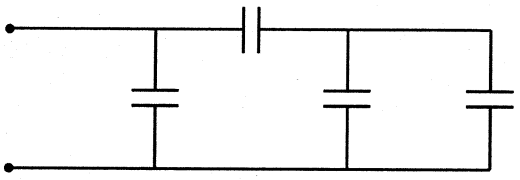
(A) 


(B) 


(C) 


(D) 


(E) 

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

(A) $3C/5$

(B) $4C/3$

(C) $5C/3$

(D) $3C$

(E) $4C$

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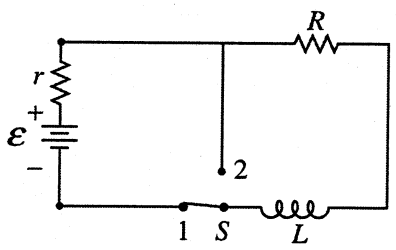
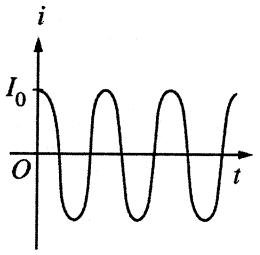
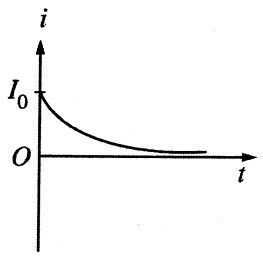



19. The circuit shown above consists of a battery of emf $\mathcal{E}$ and internal resistance $r$, a resistor $R$, an inductor $L$, and a switch $S$, initially in position 1. After the current $i$ in the inductor reaches its maximum value $I_0$, $S$ is switched instantaneously from position 1 to position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

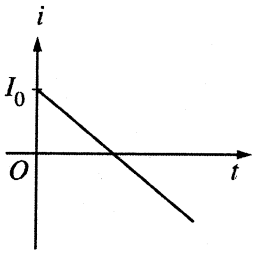
(A)



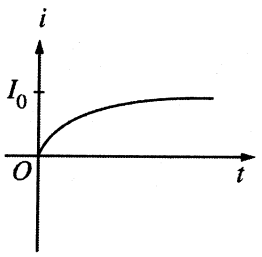

(B)



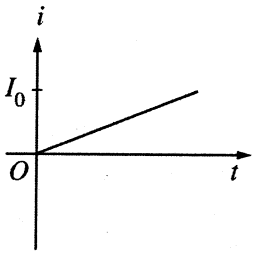

(C)




(D)




(E)

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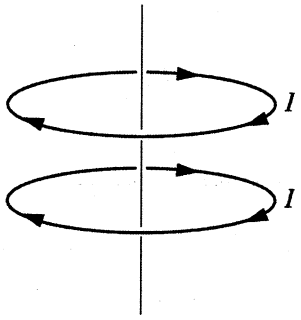


20. Two conducting loops that are centered on the same axis carry equal currents $I$ in the same direction as shown in the diagram above. If the current in the upper loop suddenly decreases to zero, what happens to the current in the lower loop according to Lenz's law?

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

**Questions 21-22**

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

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

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

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

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

---

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

(A) $\frac{1}{8}P$
(B) $\frac{1}{4}P$
(C) $P$
(D) $4P$
(E) $8P$

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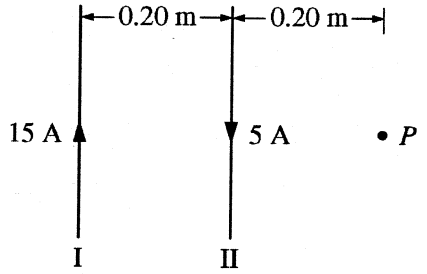
**Questions 24-25**




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

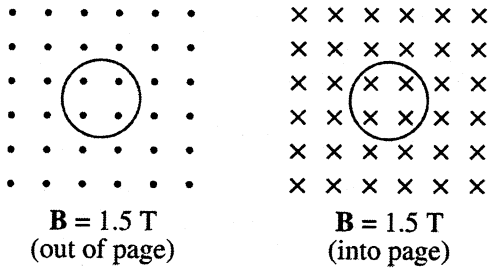
24. What is the magnitude of the net magnetic field at point *P*, located 0.20 m to the right of wire II ?

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

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

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

**Questions 26-27**




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

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

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

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

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

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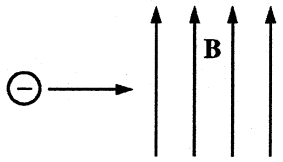
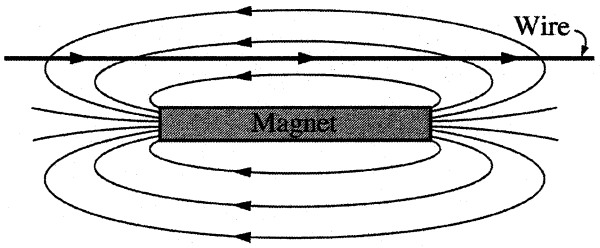



28. An electron moving to the right with constant velocity enters a region with a uniform magnetic field **B** directed toward the top of the page, as shown above. In what direction will the electron initially be deflected?

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




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

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

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GO ON TO THE NEXT PAGE.

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

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

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

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

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

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

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

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

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

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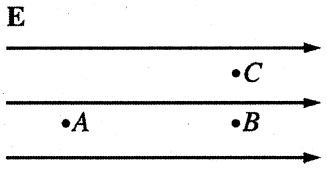
34. A conducting spherical shell $S$ has a charge $Q$ distributed over its surface. The total electric flux through any imaginary concentric spherical shell of radius $r$ that encloses $S$ is

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




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

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

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

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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.**

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

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

# AP® Physics C: Mechanics Exam

## SECTION II: Free Response

**2014**

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

### At a Glance

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

### IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐
   First letter of your first name ☐
2. Date of birth
   ☐☐ Month ☐☐ Day ☐☐☐☐ Year
3. Six-digit school code
   ☐☐☐☐☐☐
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   No, I do not grant the College Board these rights. ☐

### Instructions

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

All final numerical answers should include appropriate units. Credit for your work depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should show your work for each part in the space provided after that part. If you need more space, be sure to clearly indicate where you continue your work. Credit will be awarded only for work that is clearly designated as the solution to a specific part of a question. Credit also depends on the quality of your solutions and explanations, so you should show your work.

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

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

**Form I**
**Form Code 4JBP6-S**

80

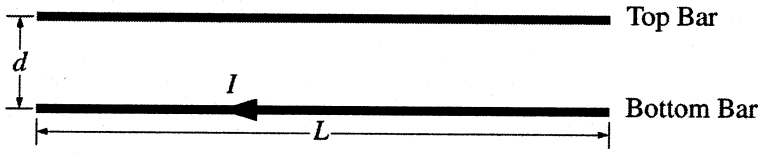
## PHYSICS C: ELECTRICITY AND MAGNETISM

### SECTION II

**Time—45 minutes**

**3 Questions**

**Directions:** Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.




E&M 1.

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

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

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

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

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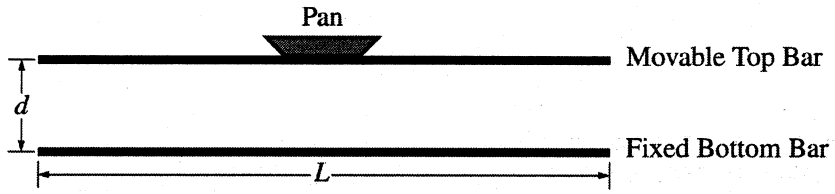
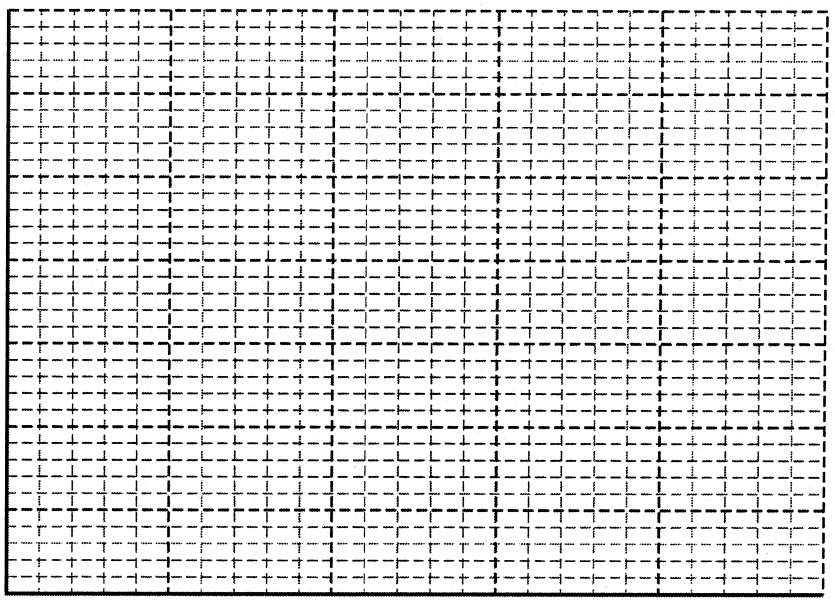
GO ON TO THE NEXT PAGE.

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




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

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



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**GO ON TO THE NEXT PAGE.**

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

(f) The length of the bars $L$ is 10.2 cm. The center-to-center distance $d$ between the bars is 6.24 mm. Using the equation of the line determined in part (e), calculate a numerical value for the vacuum permeability $\mu_0$.

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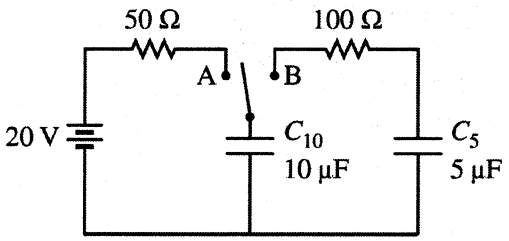


E&M 2.

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

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

i. Current in the 50 Ω resistor

ii. Current in the 100 Ω resistor

(b)

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

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

____ Positive ____ Negative

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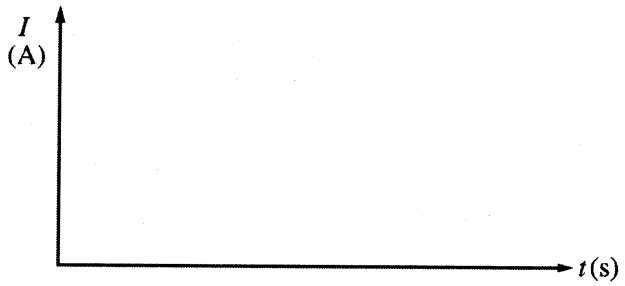
Some time later, the switch is moved to position B.

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




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

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

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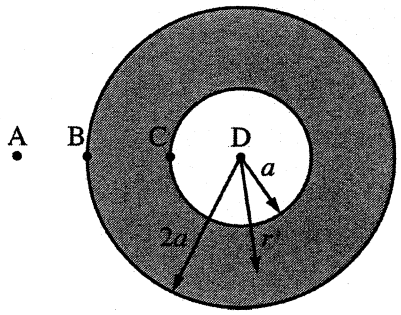


E&M 3.

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

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

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

i. $r > 2a$

ii. $r < a$

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

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

____ A ____ B ____ C ____ D

Justify your rankings.

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THIS PAGE MAY BE USED FOR SCRATCH WORK.

**STOP**

**END OF EXAM**

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

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

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

Question 1: A

Question 2: C

Question 3: E

Question 4: A

Question 5: C

Question 6: D

Question 7: C

Question 8: A

Question 9: C

Question 10: C

Question 11: A

Question 12: A

Question 13: C

Question 14: E

Question 15: B

Question 16: A

Question 17: D

Question 18: C

Question 19: B

Question 20: D

Question 21: A

Question 22: D

Question 23: E

Question 24: C

Question 25: C

Question 26: C

Question 27: D

Question 28: C

Question 29: E

Question 30: C

Question 31: C

Question 32: B

Question 33: C

Question 34: E

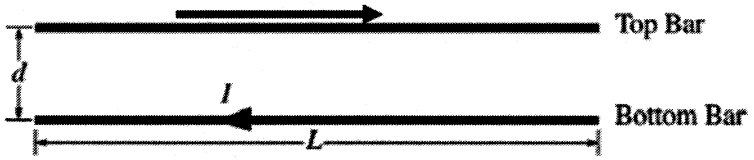
Question 35: C

# AP® PHYSICS C - ELECTRICITY AND MAGNETISM
# 2014 SCORING GUIDELINES

## Question 1

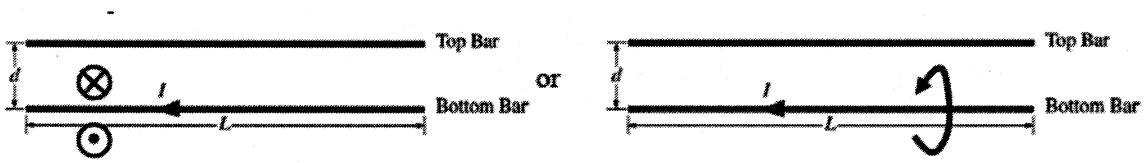
**15 points total** **Distribution of points**

(a) 1 point




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

(b) 2 points




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

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

OR

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

(c) 3 points

For using a correct expression for the magnetic force 1 point

$F = ILB$

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

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

For a correct answer 1 point

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

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# AP® PHYSICS C - ELECTRICITY AND MAGNETISM
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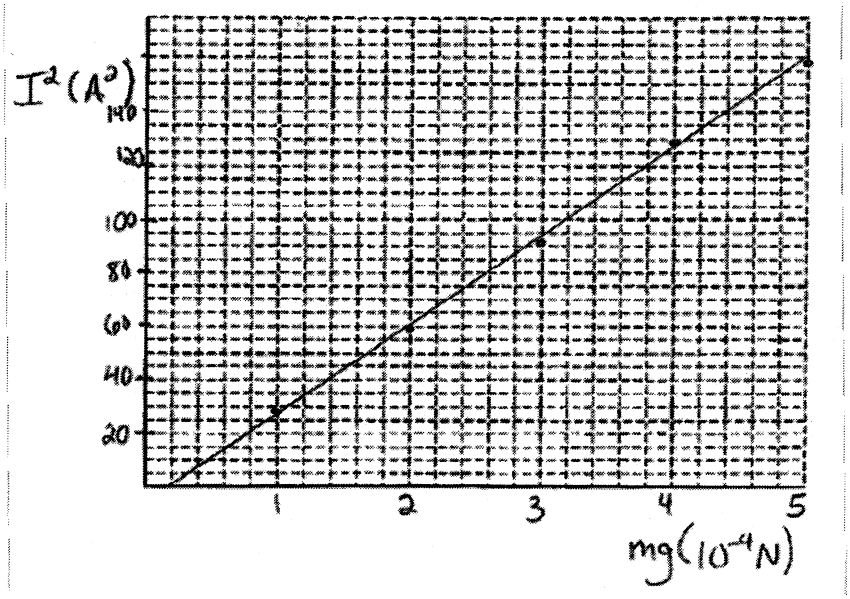
## Question 1 (continued)

**Distribution of points**

(d) 3 points




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

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

For correctly plotting the data points — 1 point

(e) 3 points

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

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

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

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

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

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

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## Question 1 (continued)

**Distribution of points**

(f) 3 points

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

$F_{net} = 0$

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

For correctly substituting the slope and given values into the above equation — 1 point

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

$$\mu_0 = \frac{(2\pi)(0.00624\ \text{m})}{(0.102\ \text{m})\left(3.24 \times 10^5\ \text{A}^2/\text{N}\right)}$$

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

$\mu_0 = 1.19 \times 10^{-6}\ \text{T}\cdot\text{m/A}$

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# AP® PHYSICS C - ELECTRICITY AND MAGNETISM
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## Question 2

**15 points total**

**Distribution of points**

(a)

i. 2 points

For using Ohm's law
$I = \frac{V}{R} = \frac{(20\ \text{V})}{(50\ \text{W})}$ — 1 point

For a correct answer with units
$I = 0.40\ \text{A}$ — 1 point

ii. 1 point

For a correct answer
$I = 0$ — 1 point

(b)

i. 2 points

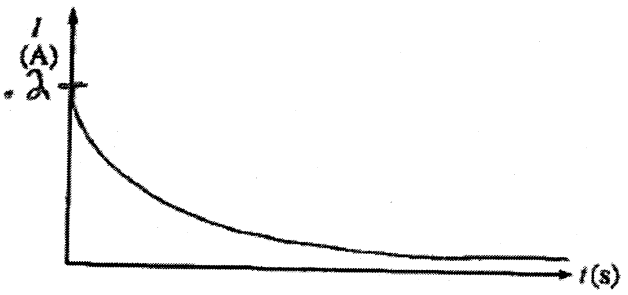
For using the equation for the charge stored in a capacitor
$Q = CV = (10\ \mu\text{F})(20\ \text{V})$ — 1 point

For an answer with units
$Q = 2.0 \times 10^{-4}\ \text{C}$ — 1 point

ii. 1 point

For selecting "Negative" — 1 point

(c) 2 points




For indicating the correct maximum current — 1 point

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

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## Question 2 (continued)

**Distribution of points**

(d) 4 points

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

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

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

$V_{10} = V_5$

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

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

$Q_{10} = 2Q_5$

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

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

For a correct answer for the 5 μF capacitor — 1 point

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

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

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

For a correct answer for the 10 μF capacitor — 1 point

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

(e) 3 points

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

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

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

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

For a correct answer — 1 point

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

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# AP® PHYSICS C - ELECTRICITY AND MAGNETISM
# 2014 SCORING GUIDELINES

## Question 3

**15 points total**

**Distribution of points**

(a) 5 points

For expressing the charge as an integral of the charge density — 1 point

$q = \int \rho dV$

For a correct expression of the volume element — 1 point

$dV = 4\pi r^2 dr$

For correctly substituting into the integral — 1 point

$q = \int br^2 \left(4\pi r^2\right) dr$

$q = 4\pi b \int r^4 dr$

For integrating with the correct limits of integration — 1 point

$q = 4\pi b \int_{r=a}^{r=2a} r^4 dr$

$q = 4\pi b \left[\frac{r^5}{5}\right]_{r=a}^{r=2a} = \frac{4\pi b}{5}\left(32a^5 - a^5\right)$

For a correct answer — 1 point

$q = \frac{124}{5}\pi b a^5$

(b)

i. 2 points

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

$\frac{q}{\varepsilon_0} = \oint E \cdot dA = E\left(4\pi r^2\right)$

For correctly substituting the answer from part (a) into Gauss's law — 1 point

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

Correct answer

$E = \frac{31 b a^5}{5\varepsilon_0 r^2}$

ii. 1 point

For a correct answer — 1 point

$E = 0$

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## Question 3 (continued)

**Distribution of points**

(c) 2 points

For a correct definition of the potential — 1 point

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

Substituting for the charge and the radius

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

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

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

*Alternate Solution* — *Alternate Points*

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

$$V = \int E \cdot dr$$

*Substituting for the electric field*

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

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

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

(d) 5 points

For ranking $A$ as the lowest potential — 1 point

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

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

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

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

Example:

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

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# 2014 AP Physics C: Electricity and Magnetism Scoring Worksheet

## Section I: Multiple Choice

| _____ | × 1.2857 = | _____ |
|---|---|---|
| Number Correct (out of 35) | | Weighted Section I Score (Do not round) |

## Section II: Free Response

| | | | | |
|---|---|---|---|---|
| Question 1 | _____ (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 |
|---|---|
| 53-90 | 5 |
| 41-52 | 4 |
| 35-40 | 3 |
| 26-34 | 2 |
| 0-25 | 1 |

CollegeBoard

# AP Physics C: Electricity and Magnetism Practice Exam

## From the 2013 Administration

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# AP® Physics C: Electricity and Magnetism Exam

## SECTION I: Multiple Choice

**2013**

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

**At a Glance**

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

### Instructions

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

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

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

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

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

PLACE SEAL HERE

**Form I**
**Form Code 4JBP4-S**

82

**PLACE SEAL HERE**
DO NOT seal answer sheet inside

## PHYSICS C: ELECTRICITY AND MAGNETISM
## SECTION I
### Time—45 minutes
### 35 Questions

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

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

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

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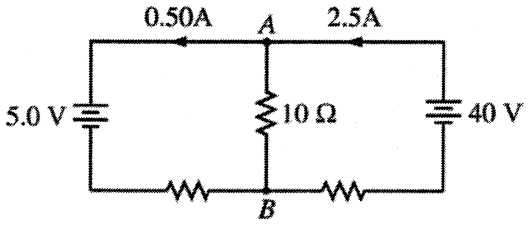
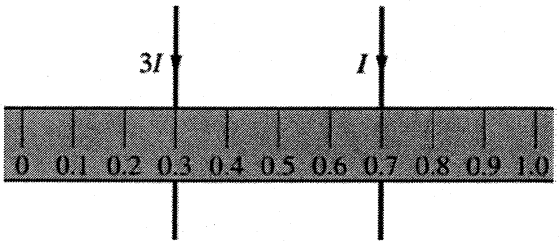



2. In the circuit shown above, a student has measured the currents that are given in the diagram, but does not know all the resistance values. The magnitude of the potential difference between points $A$ and $B$ is

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

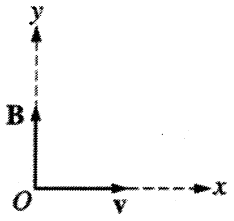
3. A 0.20 μF capacitor and a 0.10 μF capacitor are connected in parallel to a 6.0 V battery. The potential difference across the 0.20 μF capacitor is most nearly

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




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

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




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

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

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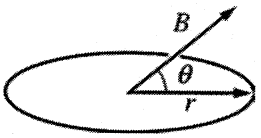
**GO ON TO THE NEXT PAGE.**




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

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

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

(C) $\pi r^2 B$

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

(E) $2\pi r B$

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

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

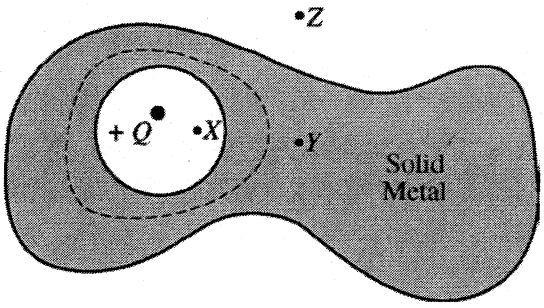
(B) $2\pi R(2bt + c)$

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

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

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

**Questions 8-10**




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

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

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

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

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

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

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

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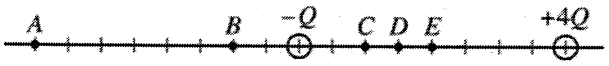


11. Two small spheres having charges $-Q$ and $+4Q$ are situated as shown above. The electric force on a small test charge will be zero if it is placed at point

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

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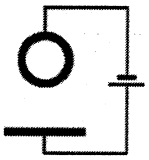


12. A conducting plate and a conducting cylinder are connected to a battery, as shown above. Which of the following best represents the electric field between the two objects?

(A) 

(B) 

(C) 

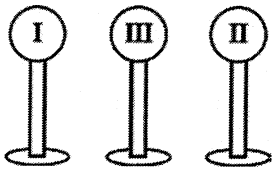
(D) 

(E) 

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

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

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




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

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

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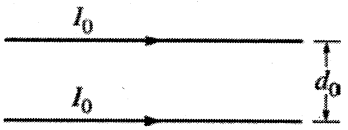
15. Which of the following describes the electric field and electric potential inside a charged solid spherical conductor that is in electrostatic equilibrium?

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

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

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




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

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

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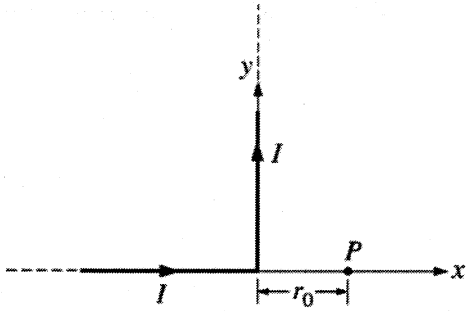
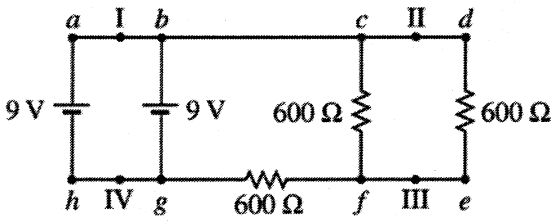



18. Suppose that the magnetic field due to a very long straight wire carrying current $I$ has magnitude $B_0$ at a distance $r_0$ from the wire. If the wire is bent into a right angle and placed on the $xy$-axes as shown above, the magnitude of the magnetic field at point $P$ on the $x$-axis at a distance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

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

**Questions 19-21**




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

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

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

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

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

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

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

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

(A) 0

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

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

(D) $6\epsilon_0 q$

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

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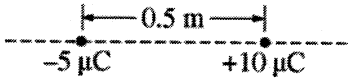
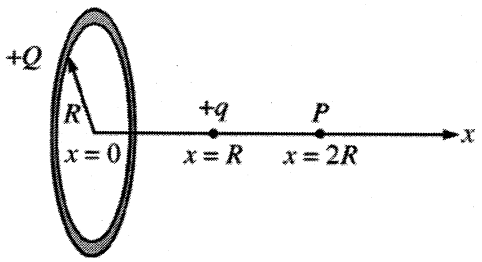



23. A negative 5 μC charge is located 0.5 m from a positive 10 μC charge as shown above. At how many positions (excluding infinity) on a line passing through both charges is the electric potential equal to zero?

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




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

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

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

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

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

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

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

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

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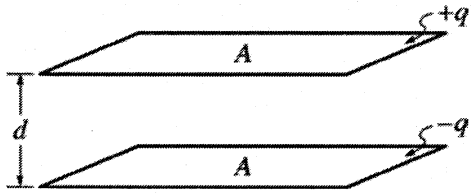



26. A parallel-plate capacitor of capacitance $C$ consists of two plates of area $A$ separated by distance $d$ as shown above. The upper and lower plates are given a net charge of $+q$ and $-q$, respectively. What is the electric field between the plates?

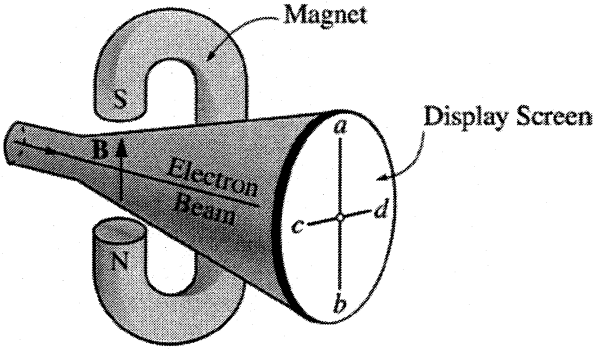
(A) Zero
(B) $\frac{C}{2qd}$
(C) $\frac{C}{qd}$
(D) $\frac{2q}{Cd}$
(E) $\frac{q}{Cd}$

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

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

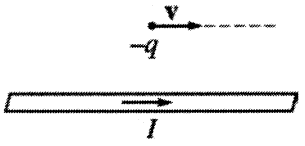
28. A compass needle is in a uniform magnetic field **B** with its north-seeking pole pointing in the direction of the field. The net magnetic force on the compass needle is

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




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

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




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

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

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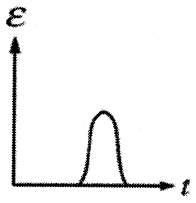
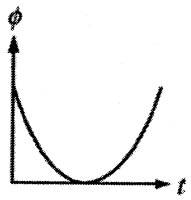
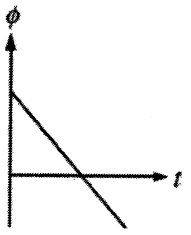
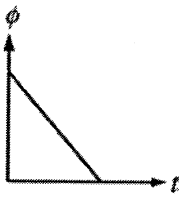
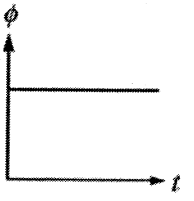


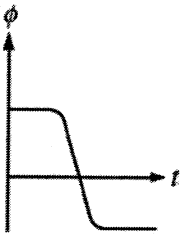

31. The graph above shows an emf $\mathcal{E}$ induced in a loop of wire as a function of time $t$. Which of the following graphs best corresponds to the magnetic flux passing through the loop of wire as a function of time $t$ ?

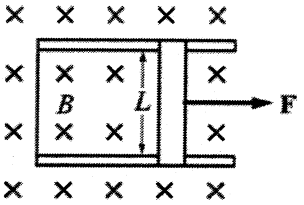
(A) 


(B) 


(C) 


(D) 


(E) 


Top View

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

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

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

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

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

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

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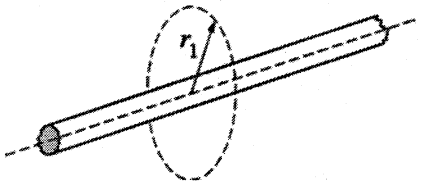



33. An electric field is produced by the very long, uniformly charged rod shown above. If the strength of the electric field is $E_1$ at a distance $r_1$ from the axis of the rod, at what distance from the axis is the field strength $\frac{E_1}{10}$?

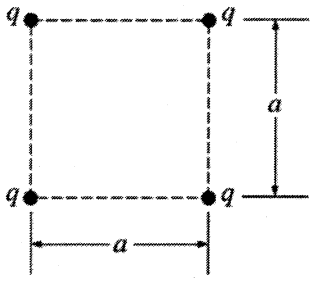
(A) $\frac{r_1}{100}$

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

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

(D) $10\, r_1$

(E) $100\, r_1$




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

(A) zero

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

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

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

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

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

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

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

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

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

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

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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.**

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

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

# AP® Physics C: Electricity and Magnetism Exam

## SECTION II: Free Response

**2013**

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

### At a Glance

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

### IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐
   First letter of your first name ☐
2. Date of birth
   ☐☐ Month ☐☐ Day ☐☐☐☐ Year
3. Six-digit school code
   ☐☐☐☐☐☐
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   No, I do not grant the College Board these rights. ☐

### Instructions

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

All final numerical answers should include appropriate units. Credit for your work depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should show your work for each part in the space provided after that part. If you need more space, be sure to clearly indicate where you continue your work. Credit will be awarded only for work that is clearly designated as the solution to a specific part of a question. Credit also depends on the quality of your solutions and explanations, so you should show your work.

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

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

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

82

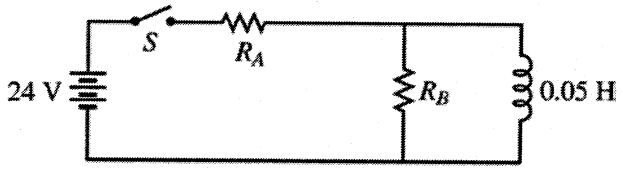
## PHYSICS C: ELECTRICITY AND MAGNETISM

### SECTION II

**Time—45 minutes**

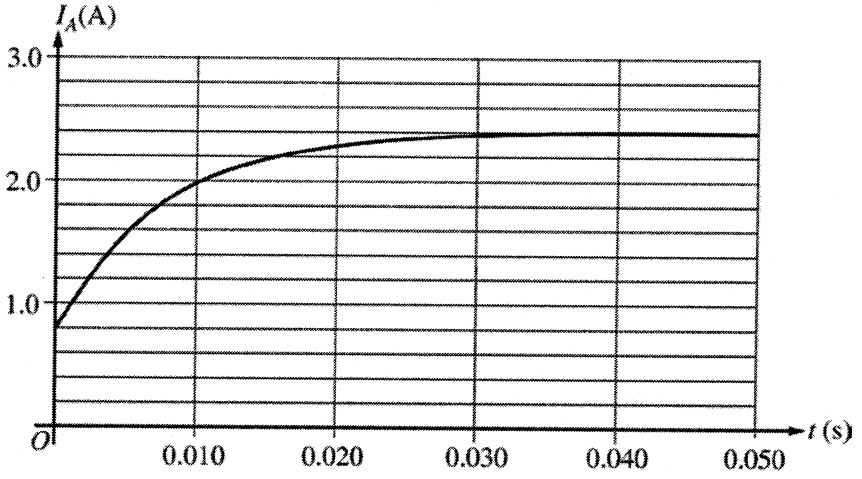
**3 Questions**

**Directions:** Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.




E&M. 1.

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




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

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

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GO ON TO THE NEXT PAGE.

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

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

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

_____ Greater than _____ Less than

Justify your answer.

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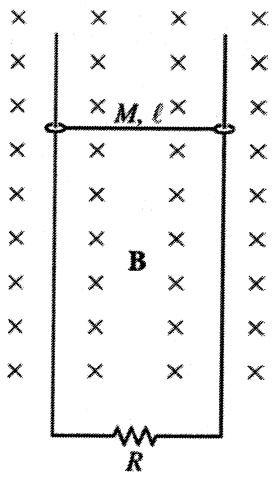


E&M. 2.

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

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

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

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

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

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GO ON TO THE NEXT PAGE.

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

(d) Determine this terminal velocity.

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

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

_____Greater than _____Less than _____Equal to

Justify your answer.

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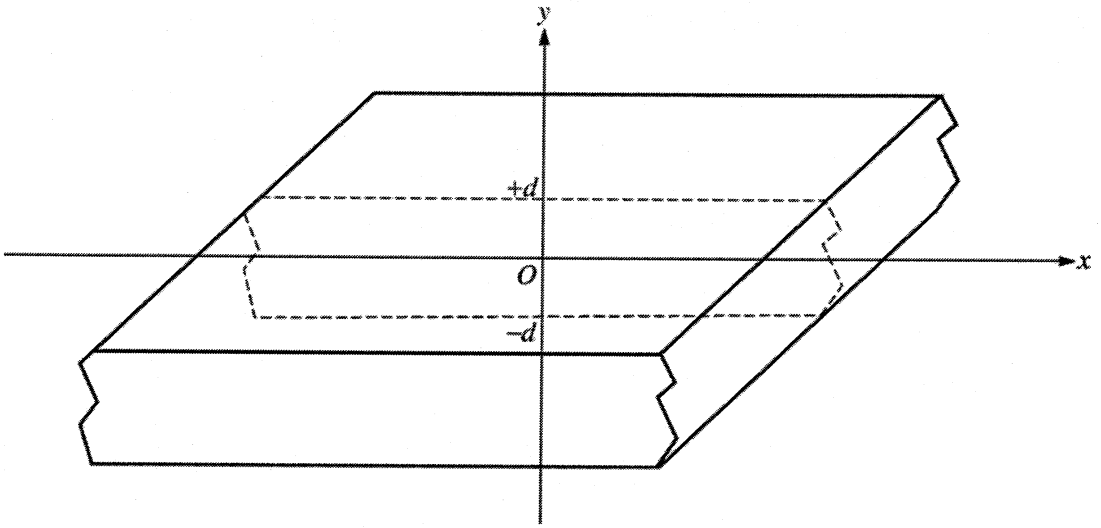
GO ON TO THE NEXT PAGE.



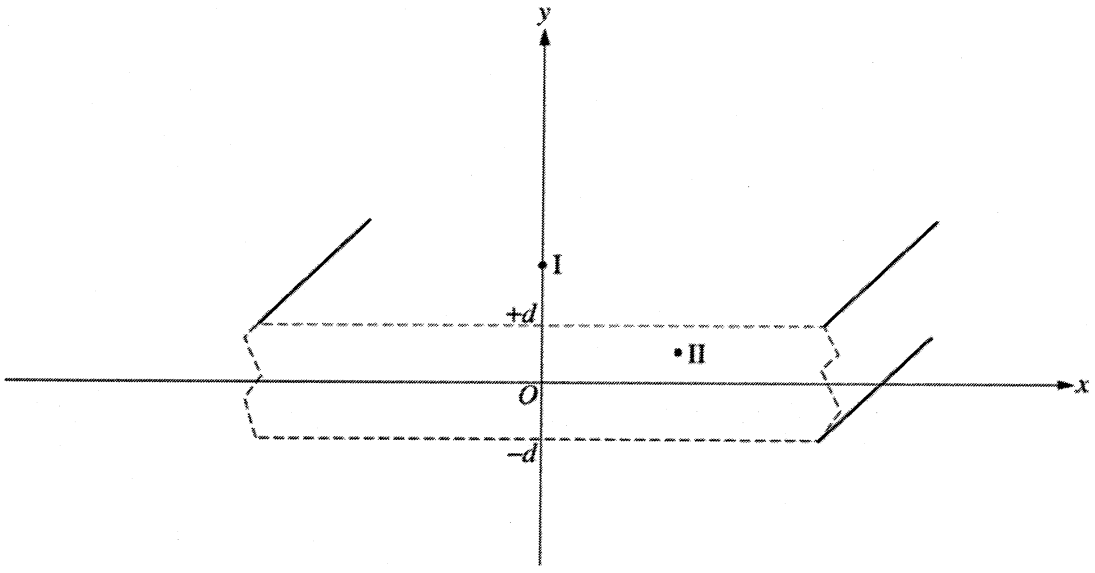

E&M. 3.

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

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

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

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

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

i. Point I $(y > d)$

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

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

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THIS PAGE MAY BE USED FOR SCRATCH WORK.

**STOP**

**END OF EXAM**

---

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

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

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

Question 1: B

Question 2: B

Question 3: E

Question 4: D

Question 5: A

Question 6: A

Question 7: E

Question 8: B

Question 9: B

Question 10: E

Question 11: A

Question 12: E

Question 13: B

Question 14: E

Question 15: D

Question 16: A

Question 17: E

Question 18: C

Question 19: E

Question 20: E

Question 21: C

Question 22: C

Question 23: C

Question 24: E

Question 25: A

Question 26: E

Question 27: A

Question 28: E

Question 29: D

Question 30: A

Question 31: E

Question 32: D

Question 33: D

Question 34: E

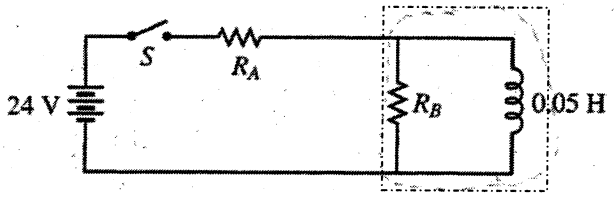
Question 35: D

# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2013 SCORING GUIDELINES

## Question 1

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

(a) 1 points




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

(b) 3 points

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

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

$V = IR_A$

For correct substitutions into the above equation — 1 point

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

For a correct answer — 1 point

$R_A = 10\ \Omega$

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

(c) 4 points

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

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

$V = I(R_A + R_B)$

$V/I = (R_A + R_B)$

$R_B = V/I - R_A$

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

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

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

$R_B = 20\ \Omega$

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## Question 1 (continued)

**Distribution of points**

(d) 5 points

The voltage across the inductor is equal to the voltage across resistor $R_B$

For using the correct voltage across $R_B$ — 2 points

$V_B = I_{Ai}R_B$

For equating $L\frac{dI}{dt}$ and $V_B$ — 1 point

$L\frac{dI}{dt} = I_{Ai}R_B$

Solve for $dI/dt$ and substitute correct values

$\frac{dI}{dt} = \frac{I_{Ai}R_B}{L} = \frac{(0.8\text{ A})(20\ \Omega)}{(0.05\text{ H})}$

For a correct answer consistent with part (c) — 1 point

For correct units — 1 point

$\frac{dI}{dt} = 320\text{ A/s}$

(e) 2 points

For selecting "Less than" — 1 point

For a correct justification — 1 point

Example: Since $R_A$ is in series with the battery, then the $10\ \Omega$ calculated value would equal $R_A + R_{battery}$, therefore the true value would be $R_A = 10\ \Omega - R_{battery}$, which is less.

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# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2013 SCORING GUIDELINES

## Question 2

**15 points total**

**Distribution of points**

(a) 1 point

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

(b) 4 points

For a correct equation for the power dissipated in a resistor — 1 point
$P = V^2/R$

For relating the potential difference across the resistor to the emf — 1 point
$V = \mathcal{E}$

For a correct expression of the emf in the circuit — 1 point
$\mathcal{E} = -\frac{d\phi}{dt} = B\ell v_1$

For a correct answer — 1 point
$P = (B\ell v_1)^2/R$

*Alternate Solution* — *Alternate Points*

*For a correct equation for the power dissipated in a resistor* — *1 point*
$P = I^2R$

*For a correct expression for the emf in the circuit* — *1 point*
$V = \mathcal{E} = -\frac{d\phi}{dt} = B\ell v_1$

*For a correct expression for the current in the circuit* — *1 point*
$I = V/R = B\ell v_1/R$

*For a correct answer* — *1 point*
$P = (B\ell v_1)^2/R$

(c) 3 points

For a correct expression for the magnetic force on a current-carrying wire — 1 point
$F_{mag} = I\ell B$

Substituting for the current in the above equation
$F_{mag} = (B\ell v_1/R)\ell B$

For a correct answer — 1 point
$F_{mag} = B^2\ell^2 v_1/R$

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

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## Question 2 (continued)

**Distribution of points**

(d) 2 points

For equating the magnetic force to the gravitational force when equilibrium is reached — 1 point

$F_{grav} = F_{mag}$

$Mg = B^2\ell^2 v_T / R$

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

$v_T = MgR / B^2\ell^2$

(e) 3 points

Using Newton's 2nd law

$\sum F = ma$

For correctly substituting the gravitational force into the above equation — 1 point

For correctly substituting the magnetic force into the above equation, with a minus sign — 1 point

For correctly expressing the acceleration as the derivative of the velocity — 1 point

$$Mg - \frac{B^2\ell^2}{R}v = M\frac{dv}{dt}$$

(f) 2 points

For selecting "Less than" — 1 point

For a correct justification — 1 point

Example: With a resistor added in parallel, the overall resistance will decrease. If the overall resistance decreases, the terminal velocity will decrease according to the equation in part (d).

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# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2013 SCORING GUIDELINES

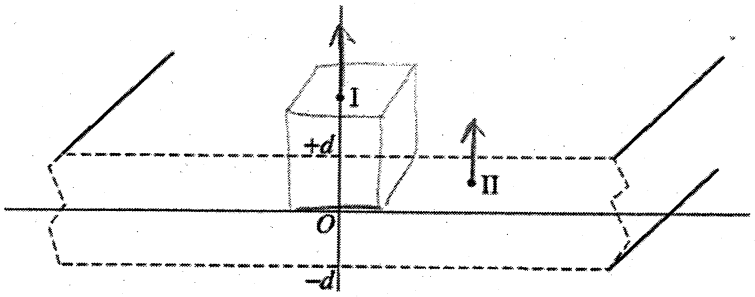
## Question 3

**15 points total**

**Distribution of points**

(a)

i. 2 points




For drawing a vector toward the top of the page in the region $y > d$ — 1 point

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

The lengths of the vectors do not matter.

ii. 4 points

For drawing any closed surface on the diagram — 1 point

For a surface with the top and bottom parallel to the $xz$-plane — 1 point

For a surface with sides parallel to the $y$-axis — 1 point

For a surface with the bottom at either $y = 0$ or $y = -d$ — 1 point

(b)

i. 3 points

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

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

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

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

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

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

For a correct answer — 1 point

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

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## Question 3 (continued)

**Distribution of points**

(b) (continued)

ii. 2 points

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

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

For a correct answer — 1 point

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

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

(c) 4 points

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

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

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

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

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

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

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

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

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

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

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

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# 2013 AP Physics C: Electricity and Magnetism Scoring Worksheet

**Section I: Multiple Choice**

| | | | |
|---|---|---|---|
| _____ | × 1.2857 = | _____ |
| Number Correct (out of 35) | | Weighted Section I Score (Do not round) |

**Section II: Free Response**

| | | | | |
|---|---|---|---|---|
| Question 1 | _____ | × 1.0000 = | _____ |
| | (out of 15) | | (Do not round) |
| Question 2 | _____ | × 1.0000 = | _____ |
| | (out of 15) | | (Do not round) |
| Question 3 | _____ | × 1.0000 = | _____ |
| | (out of 15) | | (Do not round) |

Sum = _____
Weighted Section II Score (Do not round)

**Composite Score**

| | | | | |
|---|---|---|---|---|
| _____ | + | _____ | = | _____ |
| Weighted Section I Score | | Weighted Section II Score | | Composite Score (Round to nearest whole number) |

AP Score Conversion Chart
Physics C: Electricity and Magnetism

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

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# AP Physics C: Electricity and Magnetism Practice Exam

## From the 2012 Administration

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# AP® Physics C: Electricity and Magnetism Exam

## SECTION I: Multiple Choice

**2012**

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

### At a Glance

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

### Instructions

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

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

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

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

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

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Minimum 20% post-consumer waste

**Form I**
**Form Code 4IBP4-S**
**82**

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DO NOT seal answer sheet inside

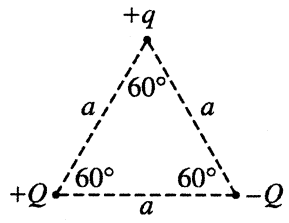
## PHYSICS C: ELECTRICITY AND MAGNETISM
## SECTION I
### Time—45 minutes
### 35 Questions

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

1. A proton moving along the positive $x$-axis enters an electric field that is directed along the positive $y$-axis. What is the direction of the electric force acting on the proton after it enters the electric field?

   (A) Along the negative $z$-axis
   (B) Along the positive $z$-axis
   (C) Along the negative $y$-axis
   (D) Along the positive $y$-axis
   (E) The direction cannot be determined since the magnitude of the electric field is not known.

**Questions 2-4**




Three particles having charges of $+q$, $+Q$, and $-Q$ are placed at the corners of an equilateral triangle of side $a$, as shown above.

2. The net force on the particle with charge $+q$ due to the other two charges is in the plane of the page and directed

   (A) vertically upward
   (B) vertically downward
   (C) horizontally to the right
   (D) horizontally to the left
   (E) toward the charge $-Q$

3. The magnitude of the force on the particle with charge $+q$ due to the other two charges is

   (A) $\frac{kqQ}{a}$

   (B) $\frac{2kqQ}{a}$

   (C) $\frac{2kqQ}{a^2}$

   (D) $\frac{2kqQ\sin 60°}{a^2}$

   (E) $\frac{2kqQ\cos 60°}{a^2}$

4. The potential energy of the particle with charge $+q$ due to the other two charges is

   (A) zero

   (B) $\frac{-2kQ}{a}$

   (C) $\frac{kqQ}{a}$

   (D) $\frac{2kqQ}{a}$

   (E) $\frac{2kqQ}{a^2}$

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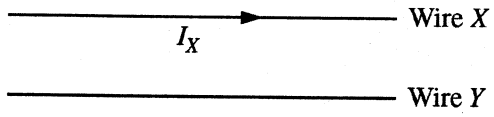
5. All the following statements about an isolated, solid charged conductor are correct EXCEPT:

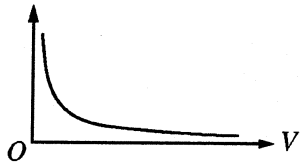
(A) All parts of the conductor are at the same potential.
(B) All excess charge resides on the outer surface.
(C) The net charge enclosed by any surface lying entirely within the conductor must equal zero.
(D) The electric field **E** just outside the conductor is directed parallel to the surface.
(E) The electric field intensity inside the conductor is zero.

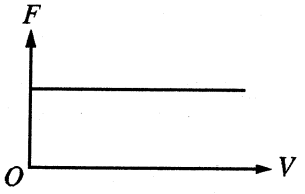
**Questions 6-8**

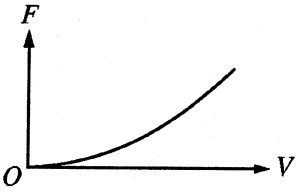


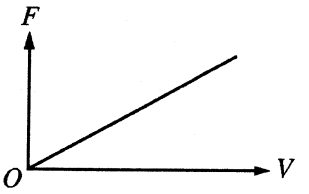

Two long, straight, parallel wires are held fixed, as shown above. A voltage is applied to wire $X$, creating a current $I_X$ to the right, and the wire experiences a magnetic force of magnitude $F_B$ toward wire $Y$.

6. Assuming the resistance of wire $X$ is constant, which of the following graphs correctly illustrates the magnitude of the magnetic force $F$ on wire $X$ as a function of the voltage $V$ applied to the wire?

(A)



(B)



(C)



(D)
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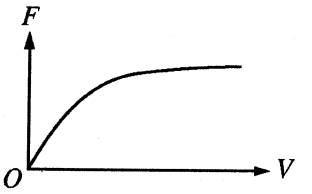


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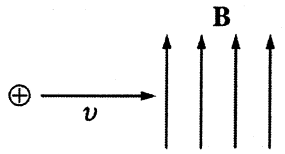
7. Which of the following could be true of wire $Y$?

I. It carries a current in the same direction as the current in wire $X$.
II. It experiences a force directed away from wire $X$.
III. It experiences a force of different magnitude than the force on wire $X$.

(A) None
(B) I only
(C) II only
(D) III only
(E) I or II

8. If the distance between the two wires is tripled, what is the magnitude of the new magnetic force exerted on wire $X$?

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




9. A proton moving to the right at constant speed $v$ enters a region containing uniform magnetic and electric fields and continues to move in a straight line. The magnetic field **B** is directed toward the top of the page, as shown above. The direction of the electric field must be

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

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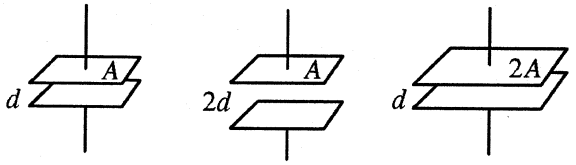
**Questions 10-11**




Capacitor I Capacitor II Capacitor III

The plate areas and separations for three capacitors are shown in the diagram above. The space between the plates in each capacitor is filled with air.

10. Suppose all three capacitors have charge $+Q$ on the top plate and charge $-Q$ on the bottom plate. Which of the following is true of the potential difference across the plates of the three capacitors?

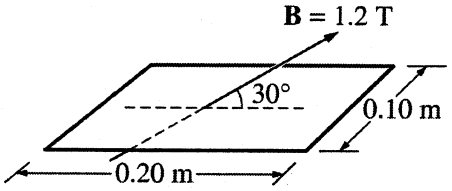
(A) It is greatest for I.
(B) It is greatest for II.
(C) It is greatest for III.
(D) It is the same for II and III and least for I.
(E) It is the same for all three capacitors.

11. Suppose all three capacitors are connected in parallel with a 9 V battery. Which of the following is true of the electric field between the plates?

(A) It is greatest for I.
(B) It is greatest for II.
(C) It is greatest for III.
(D) It is the same for I and III and least for II.
(E) It is the same for I and II and least for III.

12. The electric potential along an $x$-axis is given by the expression $V = ax - bx^2$, where $a$ and $b$ are constants. At what point on the $x$-axis is the electric field zero?

(A) $x = 0$
(B) $x = a/2b$
(C) $x = a/b$
(D) $x = 3a/2b$
(E) At no point




13. A uniform magnetic field **B** of magnitude 1.2 T passes through a rectangular loop of wire, which measures 0.10 m by 0.20 m. The field is oriented 30° with respect to the plane of the loop, as shown above. What is the magnetic flux through the loop?

(A) Zero
(B) 0.012 T·m$^2$
(C) 0.02 T·m$^2$
(D) 0.024 T·m$^2$
(E) 0.048 T·m$^2$

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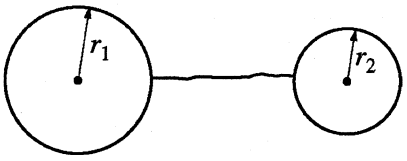


Note: Figure not drawn to scale.

14. A metal sphere with radius $r_1$ has a total electric charge of magnitude $q$. An uncharged metal sphere with radius $r_2$ (with $r_1 > r_2$) is then connected by a wire to the first sphere, as illustrated above. The separation of the spheres is much greater than the radius of either sphere. When equilibrium is reached, the spheres will have

(A) charges on their surfaces of equal magnitude and the same sign
(B) charges on their surfaces of equal magnitude and opposite sign
(C) equal electric fields at their surfaces
(D) equal capacitances
(E) equal electric potentials

15. A negatively charged conductor attracts a second object. The second object could be which of the following?

I. A conductor with positive net charge
II. A conductor with zero net charge
III. An insulator with zero net charge

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

16. Three resistors having resistances of 3 Ω, 6 Ω, and 9 Ω, respectively, are connected in parallel with a 10 V battery. True statements about the circuit include which of the following?

I. The current in the 9 Ω resistor is three times the current in the 3 Ω resistor.
II. The potential difference across each resistor is the same.
III. The power dissipated in the 9 Ω resistor is greater than the power dissipated in either of the other two resistors.

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

17. When two resistors having resistances $R_1$ and $R_2$ are connected in parallel, the equivalent resistance of the combination is 10 Ω. Which of the following statements about the resistances is true?

(A) Both $R_1$ and $R_2$ are greater than 10 Ω.
(B) Both $R_1$ and $R_2$ are equal to 10 Ω.
(C) Both $R_1$ and $R_2$ are less than 10 Ω.
(D) The sum of $R_1$ and $R_2$ is 10 Ω.
(E) One of the resistances is greater than 10 Ω, and the other is less than 10 Ω.

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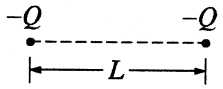



18. Two particles each with a charge $-Q$ are fixed a distance $L$ apart as shown above. Each particle experiences a net electric force $F$. A particle with a charge $+q$ is now fixed midway between the original two particles. As a result, the net electric force experienced by each negatively charged particle is reduced to $F/2$. The value of $q$ is

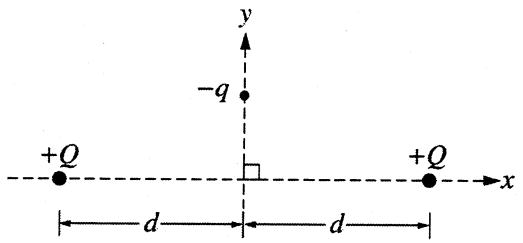
(A) $Q$

(B) $\frac{Q}{2}$

(C) $\frac{Q}{4}$

(D) $\frac{Q}{8}$

(E) $\frac{Q}{16}$




Top View

19. Two objects on a horizontal frictionless surface each have charge $+Q$ and each are fixed in place on the $x$ axis at the same distance $d$ from the origin as shown in the figure above. A particle of charge $-q$ constrained to move along the $y$ axis is released from rest. After release, the particle will

(A) stay where it is
(B) exhibit oscillatory motion
(C) move in the direction of increasing $y$
(D) move in the direction of decreasing $y$ and stop at the origin
(E) move in the direction of decreasing $y$ and keep going to negative infinity

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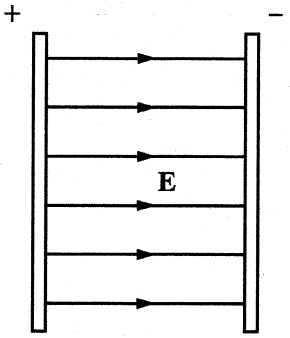


20. A uniform electric field **E** exists between the two large, oppositely charged plates shown above. If the distance between the plates is increased without changing the charges on the plates, which of the following statements can be justified?

(A) The electric field strength decreases.
(B) The electric field strength increases.
(C) The potential difference between the plates decreases.
(D) The potential difference between the plates increases.
(E) There will be no change in either the electric field strength or the potential difference.

21. When two identical resistors are connected in series to a battery, the total power dissipated is $P$. When the same two resistors are connected in parallel to the same battery, the total power dissipated is

(A) $\frac{1}{4}P$
(B) $\frac{1}{2}P$
(C) $P$
(D) $2P$
(E) $4P$

22. A positively charged particle in a uniform magnetic field is moving in a circular path of radius $r$ perpendicular to the field. How much work does the magnetic force $F$ do on the charge for half a revolution?

(A) $\pi r^2 F$
(B) $2\pi rF$
(C) $\pi rF$
(D) $2rF$
(E) Zero

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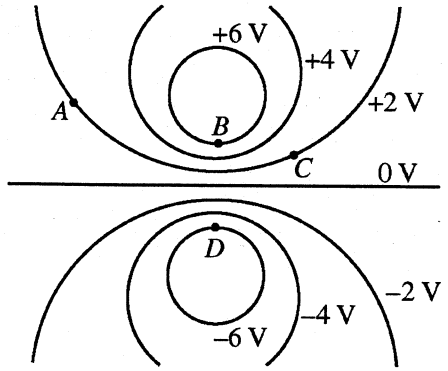
**Questions 23-25**




The diagram above shows a cross section of equipotential lines produced by a charge distribution. Points *A*, *B*, *C*, and *D* lie in the plane of the page.

23. For which two points can a negatively charged particle be moved from rest at one point to rest at the other with no work being done by the electric field?

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

24. A positively charged particle is moved by an external force from rest at one point to rest at another. For which of the following motions would net positive work be required by the external force?

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

25. The electric potential shown in the diagram could be created by which of the following?

(A) A ring of positive charge
(B) A large sheet of positive charge
(C) Two negative point charges
(D) Two long lines of charge: one positive and one negative
(E) A long line of positive charge and a negative point charge

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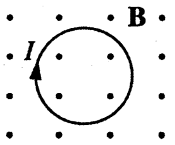
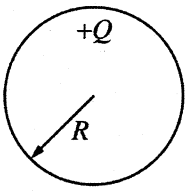
26. A magnetic field perpendicular to the plane of a wire loop is uniform in space but changes with time $t$ in the region of the loop. If the induced emf in the loop increases linearly with time $t$, then the magnitude of the magnetic field must be proportional to

(A) $t^3$
(B) $t^2$
(C) $t$
(D) $t^0$ (i.e., constant)
(E) $t^{1/2}$




27. A loop of wire carrying a steady current $I$ is initially at rest perpendicular to a uniform magnetic field of magnitude $B$, as shown above. The loop is then rotated about a diameter at a constant rate. The torque on the loop is maximum when the loop has rotated, with respect to its initial position, through an angle of

(A) 30°
(B) 45°
(C) 90°
(D) 180°
(E) 360°




28. The solid conducting sphere of radius $R$ shown above has a charge $+Q$ distributed uniformly on its surface. The potential at the center of the solid sphere is

(A) $+\frac{1}{4\pi\epsilon_0}\frac{Q}{R}$

(B) $-\frac{1}{4\pi\epsilon_0}\frac{Q}{R}$

(C) $-\frac{1}{4\pi\epsilon_0}\frac{Q}{R^2}$

(D) zero

(E) undefined

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**Questions 29-31**

A circuit consists of a resistor $R$, an inductor $L$, and an open switch $S$ connected in series with a battery. The switch is then closed at time $t = 0$.

29. If the current in the circuit is $I$ at time $t$, what energy is stored in the circuit in addition to that stored in the battery?

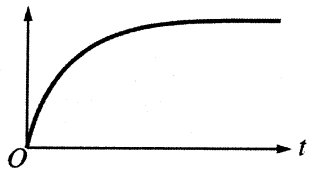
(A) $LI$

(B) $I^2R$

(C) $\frac{1}{2}LI^2$

(D) $LI + I^2R$

(E) $\frac{1}{2}LI^2 + I^2R$




30. Which of the following quantities could be represented as a function of time by the graph shown above?

I. The potential difference across the resistor
II. The potential difference across the inductor
III. The current in the circuit

(A) I only
(B) II only
(C) I and III only
(D) II and III only
(E) I, II, and III

31. The change in current when the switch is closed is determined by the inductive time constant $\tau$. If the inductance is doubled and the resistance is halved, the new inductive time constant $\tau'$ equals

(A) $\frac{1}{4}\tau$

(B) $\frac{1}{2}\tau$

(C) $\tau$

(D) $2\tau$

(E) $4\tau$

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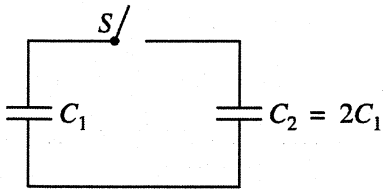
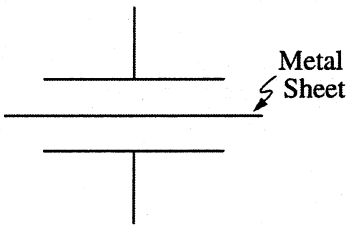



32. A capacitor of capacitance $C_1$ is charged and then connected to another initially uncharged capacitor of capacitance $C_2 = 2C_1$, as shown above, with the switch $S$ in the open position. When $S$ is closed and the system comes to equilibrium, which of the following is true of the charges on the capacitors and the potential differences across them?

| | Charge | Potential Difference |
|---|---|---|
| (A) | $Q_1 = \frac{1}{2}Q_2$ | $V_1 = \frac{1}{2}V_2$ |
| (B) | $Q_1 = \frac{1}{2}Q_2$ | $V_1 = V_2$ |
| (C) | $Q_1 = Q_2$ | $V_1 = V_2$ |
| (D) | $Q_1 = Q_2$ | $V_1 = \frac{1}{2}V_2$ |
| (E) | $Q_1 = 2Q_2$ | $V_1 = V_2$ |




33. An air-gap capacitor originally has capacitance $C$. If a thin sheet of metal is placed halfway between the plates of the capacitor without touching either plate, as shown above, the effective capacitance is

(A) $4C$
(B) $2C$
(C) $C$
(D) $C/2$
(E) $C/4$

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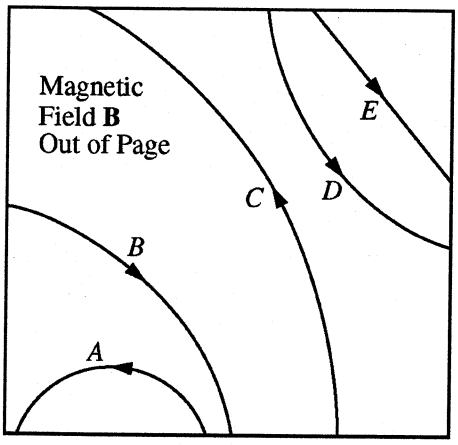
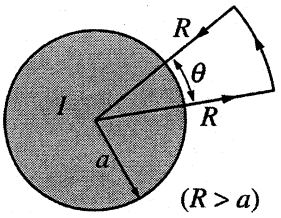



34. The figure above shows the paths of five particles as they pass through the region inside the box that contains a uniform magnetic field **B** directed out of the page. Which particle has a positive charge?

(A) *A*
(B) *B*
(C) *C*
(D) *D*
(E) *E*




35. A long, straight wire of radius $a$ carries a current $I$ out of the page, which is uniformly distributed over the cross section of the wire. The value of $\oint \mathbf{B} \cdot d\ell$, the line integral of the magnetic field **B** around the wedge-shaped path, equals which of the following?

(A) $\frac{\mu_0 \theta I}{2\pi}$

(B) $\frac{\mu_0 \theta I}{2\pi^2 a^2}$

(C) $\frac{\mu_0 \theta I}{2\pi^2 R^2}$

(D) $\frac{\mu_0 I}{\pi a^2}$

(E) $\frac{\mu_0 I}{\pi R^2}$

# STOP

**END OF ELECTRICITY AND MAGNETISM SECTION I**

**IF YOU FINISH BEFORE TIME IS CALLED,**
**YOU MAY CHECK YOUR WORK ON ELECTRICITY AND MAGNETISM SECTION I ONLY.**

**DO NOT TURN TO ANY OTHER TEST MATERIALS.**

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**MAKE SURE YOU HAVE DONE THE FOLLOWING.**

- **PLACED YOUR AP NUMBER LABEL ON YOUR ANSWER SHEET**
- **WRITTEN AND GRIDDED YOUR AP NUMBER CORRECTLY ON YOUR ANSWER SHEET**
- **TAKEN THE AP EXAM LABEL FROM THE FRONT OF THIS BOOKLET AND PLACED IT ON YOUR ANSWER SHEET**

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# AP® Physics C: Electricity and Magnetism Exam

## SECTION II: Free Response

**2012**

**DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.**

### At a Glance

**Total Time**
45 minutes
**Number of Questions**
3
**Percent of Total Score**
50%
**Writing Instrument**
Either pencil or pen with black or dark blue ink
**Electronic Devices**
Calculator allowed
**Weight**
The questions are weighted equally.

### IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐
   First letter of your first name ☐
2. Date of birth
   ☐☐ Month ☐☐ Day ☐☐☐☐ Year
3. Six-digit school code
   ☐☐☐☐☐☐

4. Unless I check the box below, I grant the College Board the unlimited right to use, reproduce, and publish my free-response materials, both written and oral, for educational research and instructional purposes. My name and the name of my school will not be used in any way in connection with my free-response materials. I understand that I am free to mark "No" with no effect on my score or its reporting.
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### 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.

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**Form I**
**Form Code 4IBP-S2**
**82**

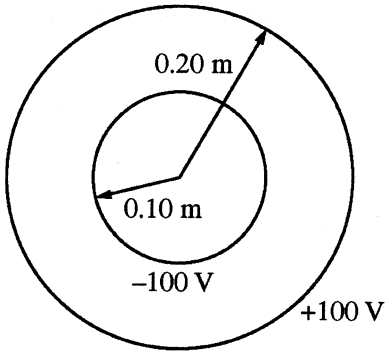
## PHYSICS C: ELECTRICITY AND MAGNETISM

### SECTION II

**Time—45 minutes**

**3 Questions**

**Directions:** Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.




E&M. 1.

Two thin, concentric, conducting spherical shells, insulated from each other, have radii of 0.10 m and 0.20 m, as shown above. The inner shell is set at an electric potential of $-100$ V , and the outer shell is set at an electric potential of +100 V, with each potential defined relative to the conventional reference point. Let $Q_i$ and $Q_o$ represent the net charge on the inner and outer shells, respectively, and let $r$ be the radial distance from the center of the shells. Express all algebraic answers in terms of $Q_i$, $Q_o$, $r$, and fundamental constants, as appropriate.

(a) Using Gauss's Law, derive an algebraic expression for the electric field $E(r)$ for $0.10 \text{ m} < r < 0.20 \text{ m}$.

(b) Determine an algebraic expression for the electric field $E(r)$ for $r > 0.20$ m .

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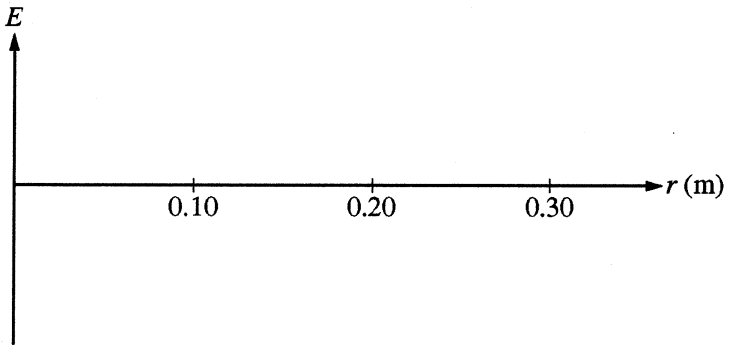
GO ON TO THE NEXT PAGE.

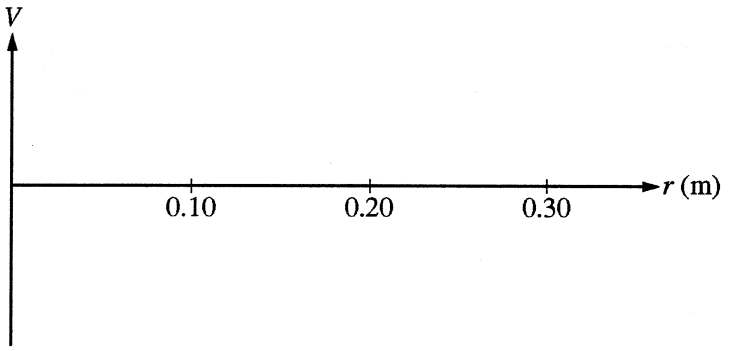
(c) Determine an algebraic expression for the electric potential $V(r)$ for $r > 0.20$ m.

(d) Using the numerical information given, calculate the value of the total charge $Q_T$ on the two spherical shells $(Q_T = Q_i + Q_o)$.

(e) On the axes below, sketch the electric field $E$ as a function of $r$. Let the positive direction be radially outward.




(f) On the axes below, sketch the electric potential $V$ as a function of $r$.

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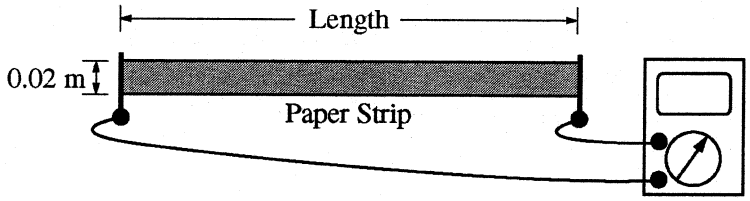
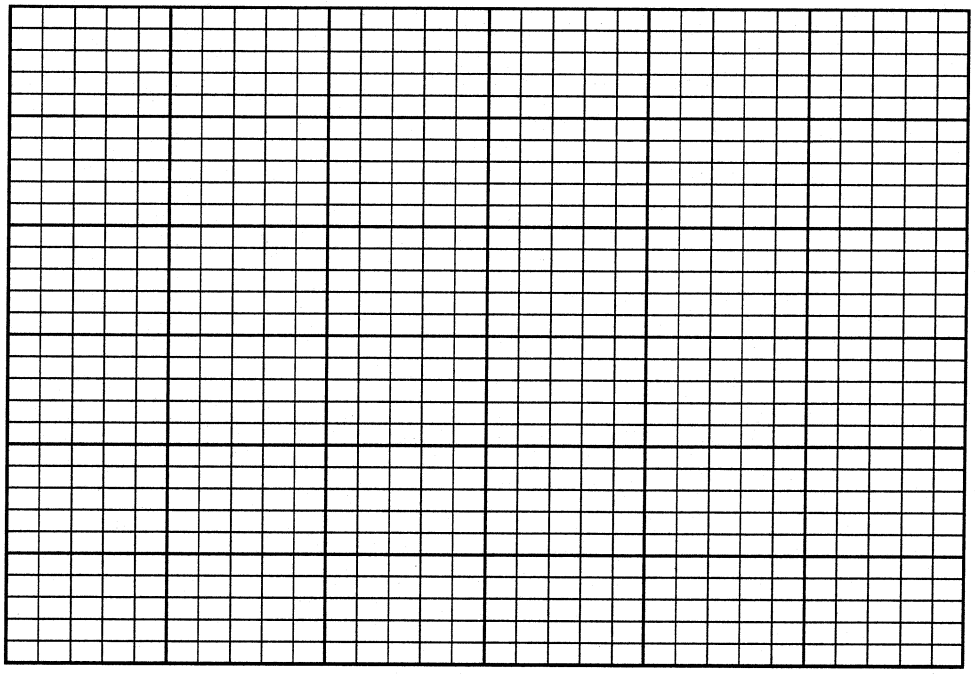



E&M. 2.

A physics student wishes to measure the resistivity of slightly conductive paper that has a thickness of $1.0 \times 10^{-4}$ m . The student cuts a sheet of the conductive paper into strips of width 0.02 m and varying lengths, making five resistors labeled R1 to R5. Using an ohmmeter, the student measures the resistance of each strip, as shown above. The data are recorded below.

| Resistor | R1 | R2 | R3 | R4 | R5 |
|---|---|---|---|---|---|
| Length (m) | 0.020 | 0.040 | 0.060 | 0.080 | 0.100 |
| Resistance ($\Omega$) | 80,000 | 180,000 | 260,000 | 370,000 | 440,000 |

(a) Use the grid below to plot a linear graph of the data points from which the resistivity of the paper can be determined. Include labels and scales for both axes. Draw the straight line that best represents the data.



(b) Using the graph, calculate the resistivity of the paper.

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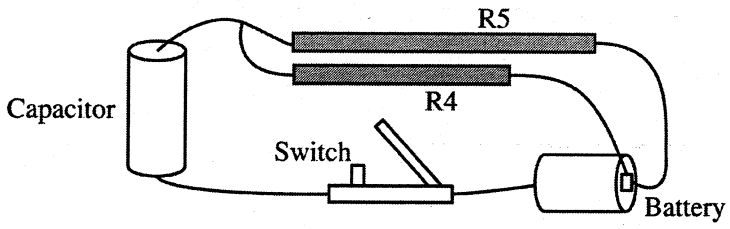
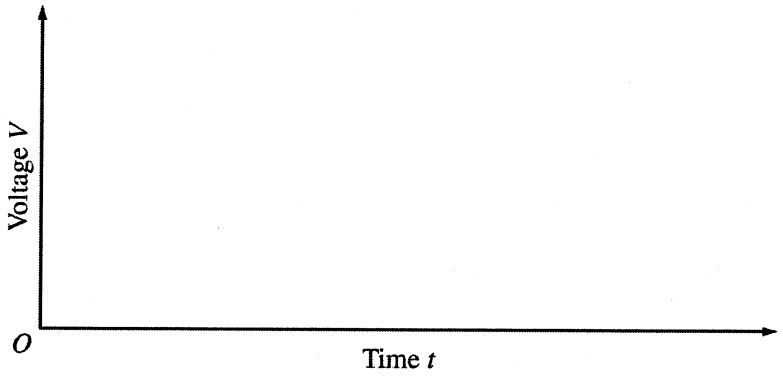



The student uses resistors R4 and R5 to build a circuit using wire, a 1.5 V battery, an uncharged 10 μF capacitor, and an open switch, as shown above.

(c) Calculate the time constant of the circuit.

(d) At time $t = 0$, the student closes the switch. On the axes below, sketch the magnitude of the voltage $V_c$ across the capacitor and the magnitudes of the voltages $V_{R4}$ and $V_{R5}$ across each resistor as functions of time $t$. Clearly label each curve according to the circuit element it represents. On the axes, explicitly label any intercepts, asymptotes, maxima, or minima with values or expressions, as appropriate.

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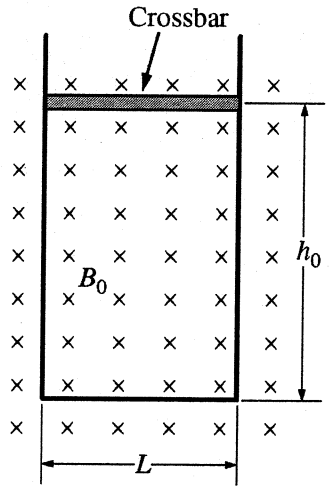


E&M. 3.

A closed loop is made of a U-shaped metal wire of negligible resistance and a movable metal crossbar of resistance $R$. The crossbar has mass $m$ and length $L$. It is initially located a distance $h_0$ from the other end of the loop. The loop is placed vertically in a uniform horizontal magnetic field of magnitude $B_0$ in the direction shown in the figure above. Express all algebraic answers to the questions below in terms of $B_0$, $L$, $m$, $h_0$, $R$, and fundamental constants, as appropriate.

(a) Determine the magnitude of the magnetic flux through the loop when the crossbar is in the position shown.

The crossbar is released from rest and slides with negligible friction down the U-shaped wire without losing electrical contact.

(b) On the figure below, indicate the direction of the current in the crossbar as it falls.



Justify your answer.

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(c) Calculate the magnitude of the current in the crossbar as it falls as a function of the crossbar's speed $v$.

(d) Derive, but do NOT solve, the differential equation that could be used to determine the speed $v$ of the crossbar as a function of time $t$.

(e) Determine the terminal speed $v_T$ of the crossbar.

(f) If the resistance $R$ of the crossbar is increased, does the terminal speed increase, decrease, or remain the same?

____ Increases ____ Decreases ____ Remains the same

Give a physical justification for your answer in terms of the forces on the crossbar.

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THIS PAGE MAY BE USED FOR SCRATCH WORK.

**STOP**

**END OF EXAM**

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**THE FOLLOWING INSTRUCTIONS APPLY TO THE COVERS OF THE SECTION II BOOKLET.**

- **MAKE SURE YOU HAVE COMPLETED THE IDENTIFICATION INFORMATION AS REQUESTED ON THE FRONT AND BACK COVERS OF THE SECTION II BOOKLET.**
- **CHECK TO SEE THAT YOUR AP NUMBER LABEL APPEARS IN THE BOX(ES) ON THE COVER(S).**
- **MAKE SURE YOU HAVE USED THE SAME SET OF AP NUMBER LABELS ON ALL AP EXAMS YOU HAVE TAKEN THIS YEAR.**

## Answer Key for AP Physics C: Electricity and Magnetism Practice Exam, Section I

| Multiple-Choice Questions | |
|---|---|
| **Question #** | **Key** |
| 1 | D |
| 2 | C |
| 3 | E |
| 4 | A |
| 5 | D |
| 6 | D |
| 7 | B |
| 8 | B |
| 9 | A |
| 10 | B |
| 11 | D |
| 12 | B |
| 13 | B |
| 14 | E |
| 15 | E |
| 16 | B |
| 17 | A |
| 18 | D |
| 19 | B |
| 20 | D |
| 21 | E |
| 22 | E |
| 23 | B |
| 24 | E |
| 25 | D |
| 26 | B |
| 27 | C |
| 28 | A |
| 29 | C |
| 30 | C |
| 31 | E |
| 32 | B |
| 33 | C |
| 34 | B |
| 35 | A |

# AP® PHYSICS
# 2012 SCORING GUIDELINES

## General Notes About 2012 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded in part (b). One exception to this practice may occur in cases where the numerical answer to a later part should easily be recognized as wrong, for example, a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if the use of an equation expressing a particular concept is worth 1 point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics Exam equation sheets. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics Course Description*.

4. The scoring guidelines typically show numerical results using the value $g = 9.8\ \text{m/s}^2$, but use of $10\ \text{m/s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer owing to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will eliminate the level of accuracy required to determine the difference in the numbers, and some credit may be lost.

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# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2012 SCORING GUIDELINES

## Question 1

**15 points total** | **Distribution of points**

(a) 3 points

For an expression of Gauss's Law — 1 point

$$\frac{Q_i}{\epsilon_0} = \oint \mathbf{E} \cdot d\mathbf{A}$$

For a correct intermediate step indicating that the area of the Gaussian surface is $4\pi r^2$ — 1 point

$$\frac{Q_i}{\epsilon_0} = E\left(4\pi r^2\right)$$

For a correct final expression, specifically using $Q_i$ — 1 point

$$E(r) = \frac{1}{4\pi\epsilon_0}\frac{Q_i}{r^2} \quad \text{or} \quad E(r) = \frac{kQ_i}{r^2}$$

(b) 2 points

For indicating that the enclosed charge is the sum of the inner and outer charges — 1 point

$$\frac{Q_i + Q_o}{\epsilon_0} = \oint \mathbf{E} \cdot d\mathbf{A}$$

For a correct expression for the electric field — 1 point

$$E(r) = \frac{1}{4\pi\epsilon_0}\frac{(Q_i + Q_o)}{r^2}$$

Note: The correct expression by itself earns both points.

(c) 2 points

For using the integral definition of potential in terms of electric field — 1 point

$$V(r) - V_\infty = -\int_\infty^r \mathbf{E} \cdot d\mathbf{r}$$

$$V(r) = -\int_\infty^r \frac{1}{4\pi\epsilon_0}\frac{(Q_i + Q_o)}{r^2} dr$$

$$V(r) = -\frac{(Q_i + Q_o)}{4\pi\epsilon_0}\left[-\frac{1}{r}\right]_\infty^r$$

For the correct expression — 1 point

$$V(r) = \frac{1}{4\pi\epsilon_0}\frac{(Q_i + Q_o)}{r}$$

Note: The correct expression by itself earns both points.

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# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2012 SCORING GUIDELINES

## Question 1 (continued)

**Distribution of points**

(c) continued

*Alternate solution* — *Alternate points*

*Outside the shells, the charges on each can be treated as point charges at their centers.*

*For using the concept of summation of point charge potentials* — *1 point*

$$V(r) = \frac{1}{4\pi\epsilon_0}\sum_j \frac{q_j}{r_j}$$

$$V(r) = \frac{1}{4\pi\epsilon_0}\left(\frac{Q_i}{r} + \frac{Q_o}{r}\right)$$

*For the correct expression (the correct expression by itself earns both points)* — *1 point*

$$V(r) = \frac{1}{4\pi\epsilon_0}\frac{(Q_i + Q_o)}{r}$$

(d) 1 point

The answer from part (c), with $Q_T = Q_i + Q_o$, can be solved for $Q_T$. Values at the outer shell are then used to determine a numerical value.

For correct work resulting in the correct value, with units — 1 point

$$V(r) = \frac{1}{4\pi\epsilon_0}\frac{Q_T}{r},\ r \geq 0.20\,\text{m}$$

$$Q_T = 4\pi\epsilon_0 r V(r) = \left(\frac{(0.20\ \text{m})(100\ \text{V})}{\left(9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)}\right)$$

$$Q_T = 2.2\times10^{-9}\ \text{C}$$

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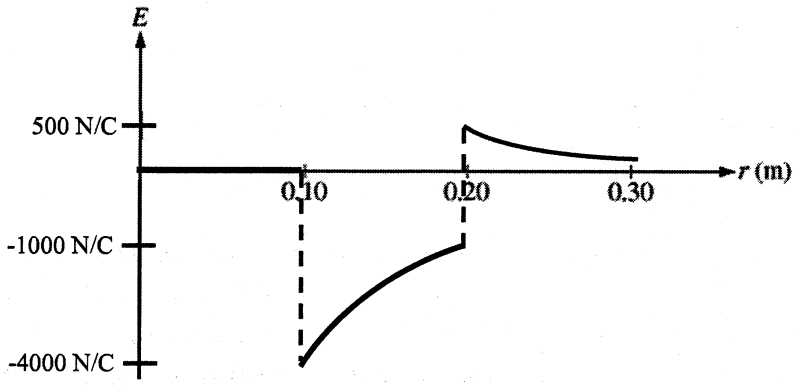
# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2012 SCORING GUIDELINES

## Question 1 (continued)

**Distribution of points**

(e) 3 points



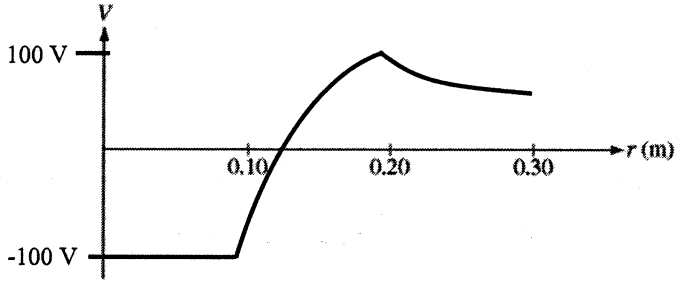

For a segment indicating an $E$-field of 0 for $r < 0.10$ m, explicitly drawn — 1 point

For a segment that is concave down and negative for $0.10 \text{ m} < r < 0.20 \text{ m}$ — 1 point

For a segment that is concave up and positive for $r > 0.20$ m. The line must not touch or cross the horizontal axis. — 1 point

Note: The labels on the vertical axis are not to scale and are not required to receive full credit.

(f) 4 points




For a continuous set of segments that have slope discontinuities at $r = 0.10$ m and at $r = 0.20$ m — 1 point

For a segment indicating a constant negative potential for $r < 0.10$ m — 1 point

For a segment that is increasing, concave down, and crosses the $r$ axis, for $0.10 \text{ m} < r < 0.20 \text{ m}$ — 1 point

For a segment that is concave up and positive for $r > 0.20$ m. The line must not touch or cross the horizontal axis. — 1 point

Note: The labels on the vertical axis are not scored and are not required to receive full credit.

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# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
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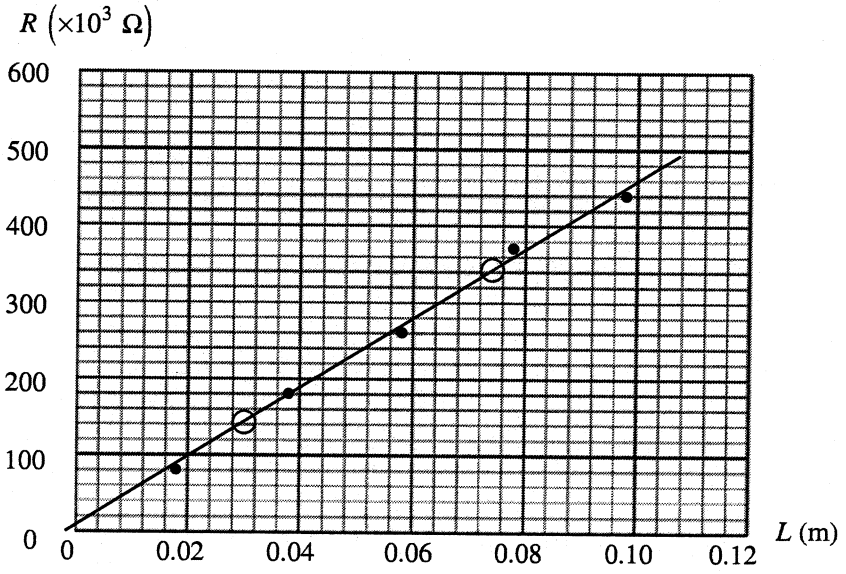
## Question 2

**15 points total**

**Distribution of points**

(a) 4 points




For a correct label on each axis (one including resistance, one including length), that leads to a linear graph — 1 point

For two linear scales, one for each axis, corresponding to the labels and occupying at least three-quarters of each axis — 1 point

For reasonably correctly plotted points according to the scale — 1 point

For a reasonable best-fit straight line — 1 point

Note: Circles on the graph are to indicate points chosen to calculate slope in part (b). They are not necessary to receive credit.

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# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2012 SCORING GUIDELINES

## Question 2 (continued)

**Distribution of points**

(b) 3 points

For correctly using the equation $R = \rho L/A$ to solve for the resistivity — 1 point

$\rho = (R/L)A$

For calculating the slope $m$ from two points that lie on the indicated best-fit line — 1 point

Example (using the two points indicated on the graph)

$m = \Delta R/\Delta L = \left(340 \times 10^3\ \Omega - 140 \times 10^3\ \Omega\right)/(0.076\ \text{m} - 0.032\ \text{m})$

$m = 4.55 \times 10^6\ \Omega/\text{m}$

Note: The slope point can also be earned for indicating that a linear regression function on a calculator was used (exact answer required): $m = 4.5 \times 10^6\ \Omega/\text{m}$ (to two significant figures).

$\rho = mA = mtw$

$\rho = \left(4.5 \times 10^6\ \Omega/\text{m}\right)\left(1.0 \times 10^{-4}\ \text{m}\right)(0.02\ \text{m})$

For a correct answer, with supporting work — 1 point

$\rho = 9.0\ \Omega\cdot\text{m}$ ($\pm 0.2\ \Omega\cdot\text{m}$ is acceptable)

(c) 3 points

For correctly stating the RC circuit time constant equation — 1 point

$\tau = RC$

For the correct value of the equivalent resistance — 1 point

$\frac{1}{R_P} = \frac{1}{R4} + \frac{1}{R5} = \frac{1}{(370\ \text{k}\Omega)} + \frac{1}{(440\ \text{k}\Omega)}$

$R_P = 201\ \text{k}\Omega$

For the correct value of the time constant (units not evaluated here) — 1 point

$\tau = R_P C = (201\ \text{k}\Omega)(10\ \mu\text{F})$

$\tau = 2.01\ \text{s}$

Units 1 point

For correct units for the answers in both parts (b) and (c) — 1 point

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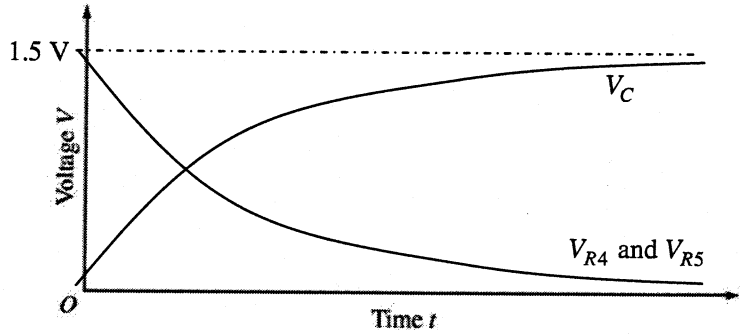
# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2012 SCORING GUIDELINES

## Question 2 (continued)

**Distribution of points**

(d) 4 points




For correctly indicating the battery voltage as an asymptote for the $V_C$ curve (or in the absence of a correct $V_C$ curve, as the maximum of the resistor curves) — 1 point

For a capacitor voltage curve starting at the origin, increasing, concave down, and appropriately labeled — 1 point

For a resistor voltage curve starting at the intersection of the asymptotic voltage with the voltage axis, decreasing and concave up (asymptotic with the time axis), and appropriately labeled — 1 point

For any indication that $V_{R4} = V_{R5}$ — 1 point

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# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2012 SCORING GUIDELINES

## Question 3

**15 points total** | **Distribution of points**

(a) 1 point

$\phi_m = \int \mathbf{B} \cdot d\mathbf{A}$

For a correct answer — 1 point

$\phi_m = B_0 L h_0$

(b) 2 points



For a correct direction arrow — 1 point

For a valid justification using Lenz's Law or the right-hand rule, if the direction is also correct — 1 point

Examples

The flux is decreasing as the area is decreasing, and a current to the right would cause an inward magnetic field that would increase flux.

The force on the falling positive charge carriers is to the right, which causes a conventional current to the right.

(c) 3 points

For a correct relationship between current, voltage, and resistance — 1 point

$I = \frac{\mathcal{E}}{R}$

For a correct relationship between the induced emf and the magnetic field — 1 point

$|\mathcal{E}| = \frac{d\phi_m}{dt}$

$|\mathcal{E}| = B_0 L \frac{dh}{dt}$

$|\mathcal{E}| = B_0 L v$

For a correct answer# — 1 point

$I = B_0 L v / R$

Note: If only the correct answer is given, with no accompanying work, only 1 point can be awarded.

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## Question 3 (continued)

**Distribution of points**

(d) 4 points

For a correct net force equation showing opposite directions for the gravitational and magnetic forces, $F_g$ and $F_M$ — 1 point

$$\sum F = ma = F_g - F_M = mg - F_M$$

$$a = g - \frac{F_M}{m}$$

For using an appropriate equation to find $F_M$ — 1 point

$$F_M = \int I\,|d\ell \times \mathbf{B}| = ILB_0$$

For substituting the current from part (c) — 1 point

$$F_M = \left(\frac{B_0 L v}{R}\right) LB_0 = \frac{B_0^2 L^2 v}{R}$$

For expressing acceleration $a$ as $dv/dt$ — 1 point

$$\frac{dv}{dt} = g - \frac{B_0^2 L^2 v}{mR}$$

(e) 2 points

For setting the gravitational force equal to the magnetic force — 1 point
$a = 0$; therefore $F_M = F_g$

For correct substitution of expressions for the forces — 1 point

$$mg = ILB_0 = B_0^2 L^2 v_T / R$$

$$v_T = \frac{mgR}{B_0^2 L^2}$$

Note: If the correct expression for $v_T$ is stated without support, 2 points are awarded.

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# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2012 SCORING GUIDELINES

## Question 3 (continued)

| | | Distribution of points |
|---|---|---|
| (f) | 3 points | |
| | For correctly checking "Increases" | 1 point |
| | Note: If an incorrect choice is made for the change in terminal speed, the justification points cannot be earned. | |
| | For indicating the inverse relationship between resistance and current | 1 point |
| | For indicating that a smaller current produces a smaller magnetic force on the bar, leading to the conclusion that to achieve a magnetic force equal to the bar's weight, the bar must be moving faster to produce the necessary current in the bar. | 1 point |
| | Note: If the only justification is stating that $v_T \propto R$ from the equation for $v_T$ in part (e), only 1 justification point is awarded, because the question specifically asks for the answer in terms of forces on the crossbar. | |

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# 2012 AP Physics C: Electricity and Magnetism Scoring Worksheet

**Section I: Multiple Choice**

| _____ | × 1.2857 = | _____ |
|---|---|---|
| Number Correct (out of 35) | | Weighted Section I Score (Do not round) |

**Section II: Free Response**

| | | | | |
|---|---|---|---|---|
| Question 1 | _____ (out of 15) | × 1.0000 = | _____ | (Do not round) |
| Question 2 | _____ (out of 15) | × 1.0000 = | _____ | (Do not round) |
| Question 3 | _____ (out of 15) | × 1.0000 = | _____ | (Do not round) |

Sum = _____
Weighted Section II Score (Do not round)

**Composite Score**

| _____ | + | _____ | = | _____ |
|---|---|---|---|---|
| Weighted Section I Score | | Weighted Section II Score | | Composite Score (Round to nearest whole number) |

AP Score Conversion Chart
Physics C: Electricity and Magnetism

| Composite Score Range | AP Score |
|---|---|
| 52-90 | 5 |
| 39-51 | 4 |
| 32-38 | 3 |
| 22-31 | 2 |
| 0-21 | 1 |