CollegeBoard
Advanced Placement
Program

AP® Physics C: Electricity and Magnetism

Practice Exam

The questions contained in this AP® Physics C: Electricity and Magnetism Practice Exam are written to the content specifications of AP Exams for this subject. Taking this practice exam should provide students with an idea of their general areas of strengths and weaknesses in preparing for the actual AP Exam. Because this AP Physics C: Electricity and Magnetism Practice Exam has never been administered as an operational AP Exam, statistical data are not available for calculating potential raw scores or conversions into AP grades.

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Contents

The College Board: Connecting Students to College Success

The College Board is a not-for-profit membership association whose mission is to connect students to college success and opportunity. Founded in 1900, the association is composed of more than 5,000 schools, colleges, universities, and other educational organizations. Each year, the College Board serves seven million students and their parents, 23,000 high schools, and 3,500 colleges through major programs and services in college admissions, guidance, assessment, financial aid, enrollment, and teaching and learning. Among its best-known programs are the SAT®, the PSAT/NMSQT®, and the Advanced Placement Program® (AP®). The College Board is committed to the principles of excellence and equity, and that commitment is embodied in all of its programs, services, activities, and concerns.

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AP Central is the official online home for the AP Program: apcentral.collegeboard.com.

AP® Physics C: Electricity and Magnetism
Directions for Administration

The AP Physics C: Electricity and Magnetism Exam is one and one-half hours in length and consists of a multiple-choice section and a free-response section.

- The 45-minute multiple-choice section contains 35 questions and accounts for 50 percent of the final grade.

- The 45-minute free-response section contains 3 questions and accounts for 50 percent of the final grade.

Students should be given a 10-minute warning prior to the end of each section of the exam. A 10-minute break should be provided before Section I is begun if students are taking Physics C: Mechanics immediately before Electricity and Magnetism.

The actual AP Physics C Exams are administered in one session, Mechanics first followed by Electricity and Magnetism. Students taking only one of the exams will have the most realistic experience if both sections are completed in one session. Similarly, students taking both Physics C exams will have the most realistic experience if both exams are completed in one session and a complete morning or afternoon is available to administer them. If a schedule does not permit one time period for administration, it would be acceptable to administer Mechanics on one day and Electricity and Magnetism on a subsequent day, or to further break things up and administer Section I and Section II of each exam on subsequent days.

Many students wonder whether or not to guess the answers to the multiple-choice questions about which they are not certain. It is improbable that mere guessing will improve a score. However, if a student has some knowledge of the question and is able to eliminate one or more answer choices as wrong, it may be to the student's advantage to answer such a question.

- The use of calculators is permitted only on Section II. Straightedges or rulers are allowed on both parts of the exam.

- It is suggested that the practice exam be completed using a pencil to simulate an actual administration.

- Teachers will need to provide paper for the students to write their free-response answers. Teachers should provide directions to the students indicating how they wish the responses to be labeled so the teacher will be able to associate the student's response with the question the student intended to answer.

- The 2008–2009 AP Physics C table of information is included as a part of Section I. The table and the AP Physics C equation lists are included with Section II. The equation lists are <u>not</u> allowed for Section I. If you use these exams in subsequent years you should download the newer versions of the table and lists from AP Central.

- Remember that students are not allowed to remove any materials, including scratch work, from the testing site.

Section I

Multiple-Choice Questions

TABLE OF INFORMATION FOR 2008 and 2009

CONSTANTS AND CONVERSION FACTORS			
Proton mass,	$m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude,	$e = 1.60 \times 10^{-19}$ C
Neutron mass,	$m_n = 1.67 \times 10^{-27}$ kg	1 electron volt,	$1\text{ eV} = 1.60 \times 10^{-19}$ J
Electron mass,	$m_e = 9.11 \times 10^{-31}$ kg	Speed of light,	$c = 3.00 \times 10^{8}$ m/s
Avogadro's number,	$N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg}\cdot\text{s}^2$
Universal gas constant,	$R = 8.31$ J/(mol•K)	Acceleration due to gravity at Earth's surface,	$g = 9.8\ \text{m/s}^2$
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K		

1 unified atomic mass unit,	$1\text{ u} = 1.66 \times 10^{-27}\text{ kg} = 931\ \text{MeV}/c^2$
Planck's constant,	$h = 6.63 \times 10^{-34}\ \text{J}\cdot\text{s} = 4.14 \times 10^{-15}\ \text{eV}\cdot\text{s}$
	$hc = 1.99 \times 10^{-25}\ \text{J}\cdot\text{m} = 1.24 \times 10^{3}\ \text{eV}\cdot\text{nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T•m)/A
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}$ (T•m)/A
1 atmosphere pressure,	$1\text{ atm} = 1.0 \times 10^{5}\ \text{N/m}^2 = 1.0 \times 10^{5}$ Pa

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

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

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

The following conventions are used in this exam.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.

II. The direction of any electric current is the direction of flow of positive charge (conventional current).

III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

PHYSICS C: ELECTRICITY AND MAGNETISM

SECTION I

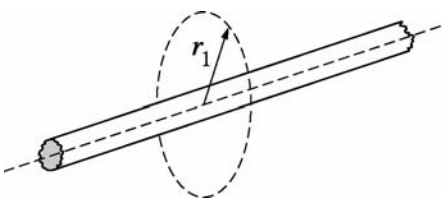
Time—45 minutes

35 Questions

Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and place the letter of your choice in the corresponding box on the student answer sheet.

1. Two negative point charges are a distance x apart and have potential energy U. If the distance between the point charges increases to $3x$, what is their new potential energy?

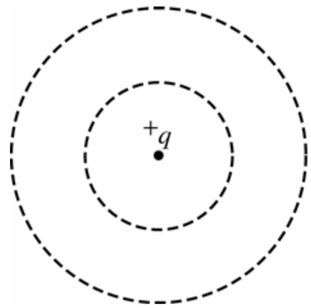
   (A) $9U$
   (B) $3U$
   (C) U
   (D) $U/3$
   (E) $U/9$



2. An electric field is produced by the very long, uniformly charged rod drawn 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 $\frac{E_1}{4}$?

   (A) $\frac{r_1}{4}$
   (B) $\frac{r_1}{2}$
   (C) $2r_1$
   (D) $4r_1$
   (E) $16r_1$

Questions 3-4



Two concentric spherical surfaces are drawn around an isolated positive charge $+q$ located at their center, as shown above. The inner surface has a radius that is $1/2$ that of the outer surface.

3. If the total electric flux passing through the inner surface is ϕ, what is the total electric flux passing through the outer surface?

   (A) $\phi/4$
   (B) $\phi/2$
   (C) ϕ
   (D) 2ϕ
   (E) 4ϕ

4. If the electric field strength at the inner surface is E, what is the electric field strength at the outer surface?

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

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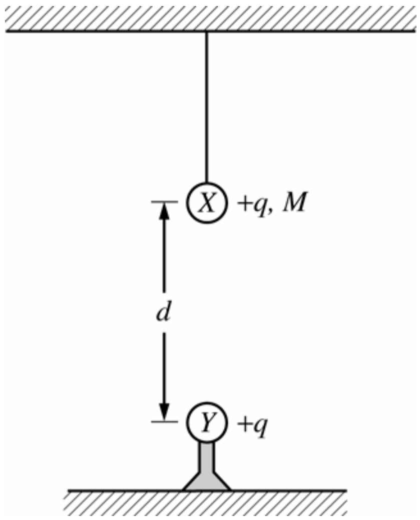


5. Sphere X of mass M and charge $+q$ hangs from a string as shown above. Sphere Y has an equal charge $+q$ and is fixed in place a distance d directly below sphere X. If sphere X is in equilibrium, the tension in the string is most nearly

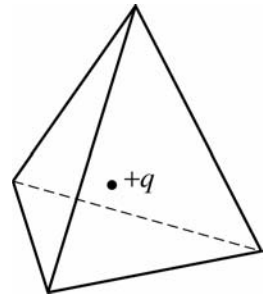
   (A) Mg

   (B) $Mg + \frac{kq}{d}$

   (C) $Mg - \frac{kq}{d}$

   (D) $Mg + \frac{kq^2}{d^2}$

   (E) $Mg - \frac{kq^2}{d^2}$



6. A charge $+q$ is placed at the center of a tetrahedron whose faces are all equilateral triangles, as shown above. What is the flux of the electric field through one face of the tetrahedron?

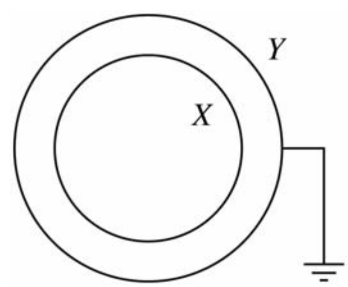
   (A) 0

   (B) $\frac{q}{\epsilon_0}$

   (C) $\frac{q}{4\epsilon_0}$

   (D) $4\epsilon_0 q$

   (E) The flux through one face cannot be determined from the information given.



7. Two concentric metal spheres X and Y are shown above. X carries a positive charge, and Y is connected to ground. True statements include which of the following?

   I. The electric field inside X is zero.
   II. The electric field outside Y is zero.
   III. The charge density on both spheres is the same.

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

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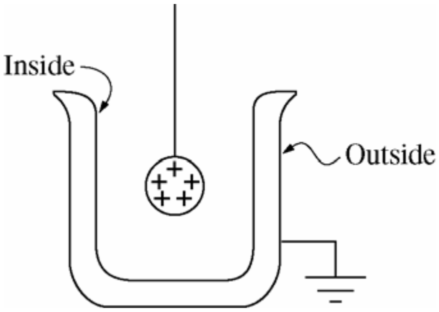
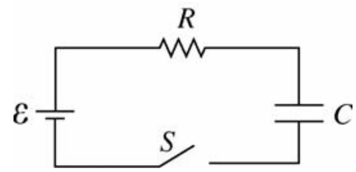
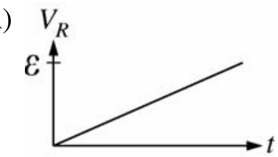


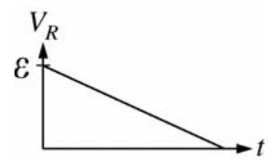
8. A small positively charged sphere is lowered by a nonconducting thread into a grounded metal cup without touching the inside surface of the cup, as shown above. The grounding wire attached to the outside surface is disconnected and the charged sphere is then removed from the cup. Which of the following best describes the subsequent distribution of excess charge on the surface of the cup?

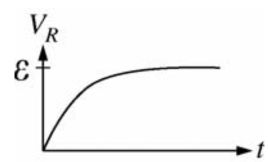
(A) Negative charge resides on the inside surface, and no charge resides on the outside surface.
(B) Negative charge resides on the outside surface, and no charge resides on the inside surface.
(C) Positive charge resides on the inside surface, and no charge resides on the outside surface.
(D) Positive charge resides on the outside surface, and no charge resides on the inside surface.
(E) Negative charge resides on the inside surface, and positive charge resides on the outside surface.

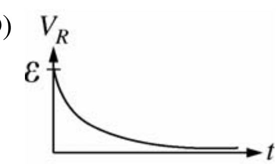


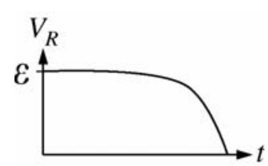
9. The capacitor C in the circuit shown above is initially uncharged. The switch S is then closed. Which of the following best represents the voltage V_R across the resistor R as a function of time t ?

(A) 

(B) 

(C) 

(D) 

(E) 

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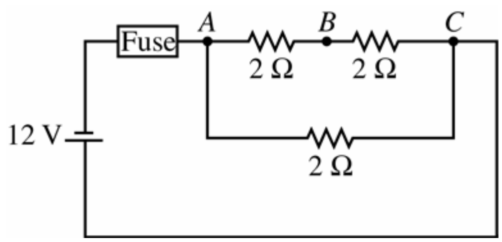
Questions 10-11



An electric circuit consists of a 12 V battery, an ideal 10 A fuse, and three 2 Ω resistors connected as shown above.

10. What would be the reading on a voltmeter connected across points A and C?

(A) 12 V
(B) 6 V
(C) 3 V
(D) 2 V
(E) 0 V, since the fuse would break the circuit

11. What would be the reading on an ammeter inserted at point B?

(A) 9 A
(B) 6 A
(C) 3 A
(D) 2 A
(E) 0 A, since the fuse would break the circuit

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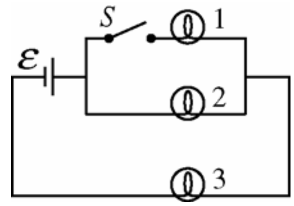
12. A fixed voltage is applied across the length of a tungsten wire. An increase in the power dissipated by the wire would result if which of the following could be increased?

(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 temperature of the wire's surroundings

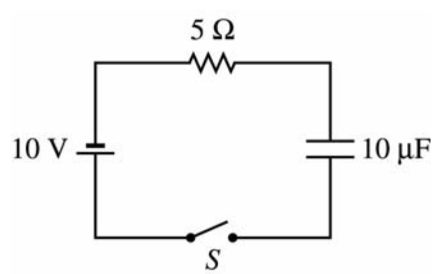


13. The three lightbulbs in the circuit above are identical, and the battery has zero internal resistance. When switch S is closed to cause bulb 1 to light, which of the other two bulbs increase(s) in brightness?

(A) Neither bulb
(B) Bulb 2 only
(C) Bulb 3 only
(D) Both bulbs
(E) It cannot be determined without knowing the emf of the battery.

14. A length of wire of resistance R is connected across a battery with zero internal resistance. The wire is then cut in half and the two halves are connected in parallel. When the combination is reconnected across the battery, what happens to the resultant power dissipated and the current drawn from the battery?

	Power	Current
(A)	No change	No change
(B)	Doubles	Doubles
(C)	Quadruples	Doubles
(D)	Doubles	Quadruples
(E)	Quadruples	Quadruples



15. In the circuit shown above, the 10 μF capacitor is initially uncharged. After the switch S has been closed for a long time, how much energy is stored in the capacitor?

(A) 0 μJ
(B) 100 μJ
(C) 250 μJ
(D) 500 μJ
(E) 1000 μJ

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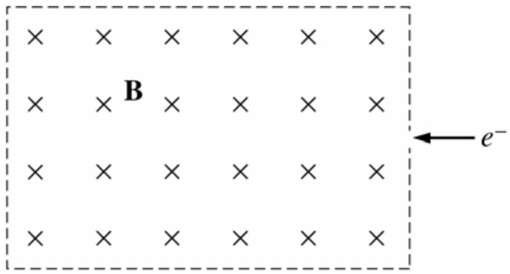
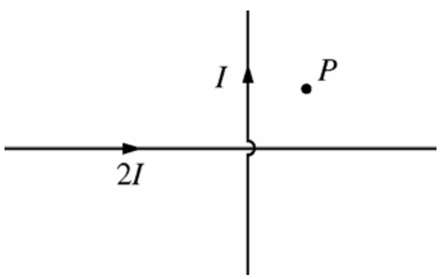


16. An electron e^- moving in the plane of the page is injected into a uniform magnetic field **B** that is perpendicular to the page, as shown above. Upon entering the field, the electron takes a path that is

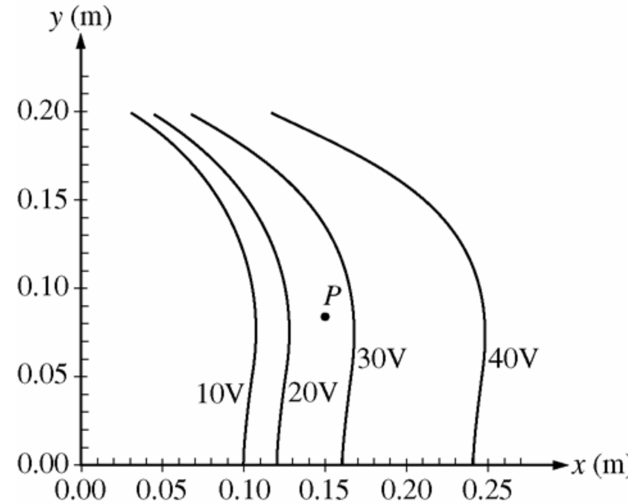
(A) straight through the field
(B) clockwise, circular, and in the plane of the page
(C) counterclockwise, circular, and in the plane of the page
(D) circular and curved out of the page
(E) circular and curved into the page



17. In the figure above, two long, straight, insulated wires at right angles in the plane of the page carry currents of I and $2I$, as shown. What is the direction of the magnetic field at point P, which is equidistant from the wires and coplanar with them?

(A) Into the page
(B) Out of the page
(C) ↘
(D) ↖
(E) ↗

Questions 18-19



A fixed charge distribution produces the equipotential lines shown in the figure above.

18. Which of the following expressions best represents the magnitude of the electric field at point P ?

(A) $\dfrac{10\text{ V}}{0.14\text{ m}}$

(B) $\dfrac{10\text{ V}}{0.04\text{ m}}$

(C) $\dfrac{25\text{ V}}{0.14\text{ m}}$

(D) $\dfrac{25\text{ V}}{0.04\text{ m}}$

(E) $\dfrac{40\text{ V}}{0.25\text{ m}}$

19. The direction of the electric field at point P is most nearly

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

20. A helium nucleus (charge $+2q$ and mass $4m$) and a lithium nucleus (charge $+3q$ and mass $7m$) are accelerated through the same electric potential difference, V_0. What is the ratio of their resultant kinetic energies, $\frac{K_{lithium}}{K_{helium}}$?

(A) $\frac{2}{3}$

(B) $\frac{6}{7}$

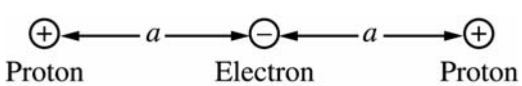
(C) 1

(D) $\frac{7}{6}$

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

21. The electric potential in the xy-plane in a certain region of space is given by $V(x,y) = 6x^2y - 2y^3$, where x and y are in meters and V is in volts. What is the magnitude of the y-component of the electric field at the point $(-1,\ 2)$?

(A) 0 V/m
(B) 4 V/m
(C) 18 V/m
(D) 24 V/m
(E) 30 V/m



22. Two protons and an electron are assembled along a line, as shown above. The distance between the electron and each proton is a. What is the work done by an external force in assembling this configuration of charges?

(A) $-2\frac{ke^2}{a}$

(B) $-\frac{3}{2}\frac{ke^2}{a}$

(C) $\frac{1}{2}\frac{ke^2}{a}$

(D) $\frac{3}{2}\frac{ke^2}{a}$

(E) $3\frac{ke^2}{a}$

Questions 23-24

A cloud contains spherical drops of water of radius R and charge Q. Assume the drops are far apart.

23. The electric field E_0 and potential V_0 at the surface of each drop is given by which of the following?

	E_0	V_0
(A)	0	0
(B)	$\frac{kQ}{R}$	$\frac{kQ}{R^2}$
(C)	$\frac{kQ}{R^2}$	$\frac{kQ}{R}$
(D)	0	$\frac{kQ}{R}$
(E)	$\frac{kQ}{R}$	0

24. If two droplets happen to combine into a single larger droplet, the new potential V at the surface of the larger droplet is most nearly equal to

(A) $3V_0$

(B) $2V_0$

(C) $\frac{2}{2^{1/3}}V_0$

(D) $2^{1/3}V_0$

(E) V_0

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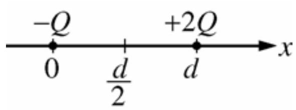


25. A point charge $-Q$ is located at the origin, while a second point charge $+2Q$ is located at $x = d$ on the x-axis, as shown above. A point on the x-axis where the net electric field is zero is located in which of the following regions?

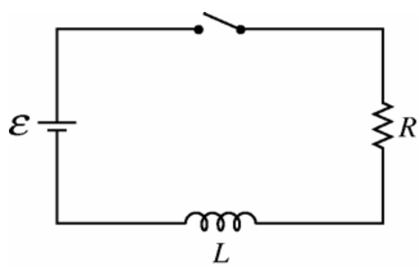
(A) $-\infty < x < 0$

(B) $0 < x < \frac{d}{2}$

(C) $\frac{d}{2} < x < d$

(D) $d < x < \infty$

(E) No region on the x-axis



26. An inductor of inductance L is connected in series with a resistor of resistance R, a battery of emf $\mathcal{E}$, and a switch, as shown above. When the switch is closed, the current I in the circuit increases with time, approaching the value I_{max}. What is I_{max}?

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

Questions 27-28

An emf of 20 V is induced around a metal ring by increasing a uniform magnetic field at a constant rate from zero to a final magnitude of 1.0×10^{-2} T throughout the region enclosed by the ring. The field direction is perpendicular to the plane of the ring.

27. If the area enclosed by the ring is $4.0 \times 10^{-3}\ \text{m}^2$, what is the time interval during which the field is increased?

(A) 2.0 μs
(B) 5.0 μs
(C) 10 μs
(D) 20 μs
(E) 50 μs

28. If the electrical resistance of the ring is 500 Ω, what is the rate at which energy is dissipated in the ring as the field is increased?

(A) 0.040 W
(B) 0.80 W
(C) 1.25 W
(D) 25 W
(E) 1.0×10^4 W

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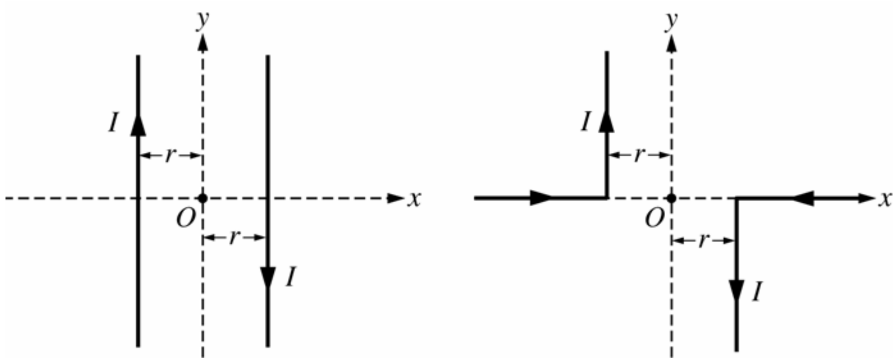


29. Two long, straight wires are parallel to and equidistant from the y-axis, as shown above left. Each carries current I in opposite directions, resulting in a magnetic field of magnitude B_0 at the origin. If the wires are each bent into right angles and placed as shown above right, what is the magnitude of the magnetic field at the origin?

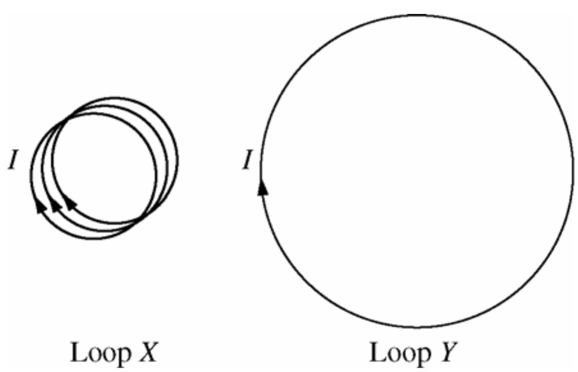
(A) Zero

(B) Between zero and $\frac{B_0}{2}$

(C) $\frac{B_0}{2}$

(D) Between $\frac{B_0}{2}$ and B_0

(E) B_0



30. A length of wire carrying a steady clockwise current I is bent to form the triple circular loop X above. An identical length of the same wire is bent less tightly to form the single loop Y of larger radius, which carries the same current I. The ratio of the magnetic field strength at the center of loop Y to the magnetic field strength at the center of loop X is

(A) $\frac{1}{9}$

(B) $\frac{1}{3}$

(C) 1

(D) 3

(E) 9

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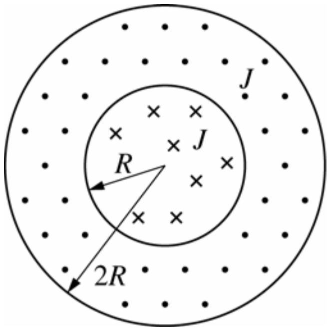


31. The diagram above shows the cross section of a long cable that has an inner wire of radius R surrounded by a conducting sheath of outer radius $2R$. The wire and the sheath carry currents in opposite directions but with the same uniform current density J. What is the magnitude of the magnetic field at the surface of the outer conductor?

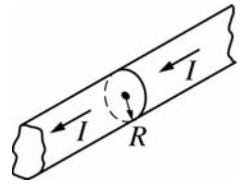
(A) Zero

(B) $\frac{1}{4}\mu_0 RJ$

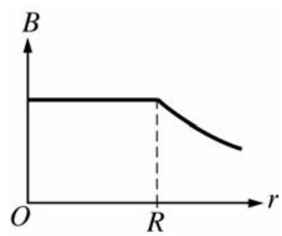
(C) $\frac{1}{2}\mu_0 RJ$

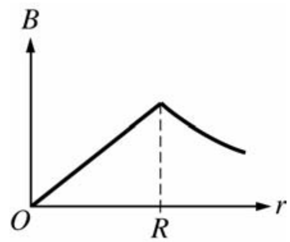
(D) $\frac{3}{4}\mu_0 RJ$

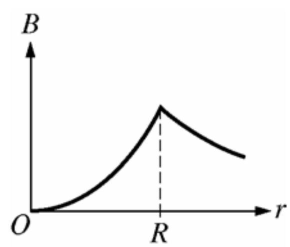
(E) $\mu_0 RJ$

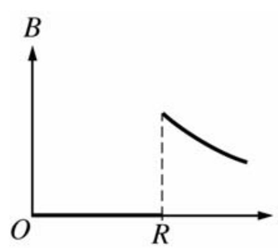


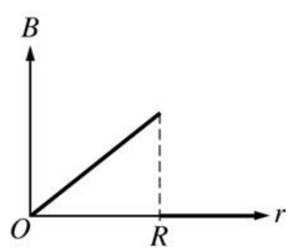
32. A long wire of radius R carries a current I, as shown above, with a current density $J = \alpha r$ that increases linearly with the distance r from the center of the wire. Which of the following graphs best represents the magnitude of the magnetic field B as a function r ?

(A)


(B)


(C)


(D)


(E)


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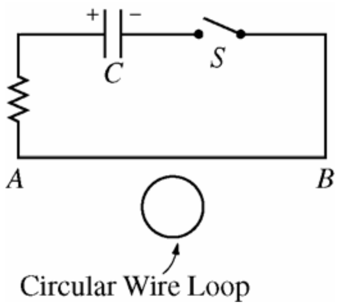


33. In the circuit drawn above, the switch S is initially open, and the capacitor C is charged with the polarity indicated. The switch is then closed, and the capacitor begins discharging through the resistor. Which of the following is true of the current that is subsequently induced in the circular wire loop near the long, straight wire AB ?

(A) It is counterclockwise and constant.
(B) It is counterclockwise and increases with time.
(C) It is counterclockwise and decreases with time.
(D) It is clockwise and increases with time.
(E) It is clockwise and decreases with time.

34. Which of the following statements contradicts one of Maxwell's equations?

(A) A changing magnetic field produces an electric field.
(B) A changing electric field produces a magnetic field.
(C) The net magnetic flux through a closed surface depends on the current inside.
(D) The net electric flux through a closed surface depends on the charge inside.
(E) The electric field due to an isolated stationary point charge is inversely proportional to the square of the distance from the charge.

35. A student building a circuit wishes to increase the frequency of an oscillator consisting of a capacitor of capacitance C and an inductor of inductance L. Which of the following would accomplish this objective?

I. Increase L
II. Increase C
III. Decrease L
IV. Decrease C

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

S T O P

END OF ELECTRICITY AND MAGNETISM SECTION I

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

DO NOT TURN TO ANY OTHER TEST MATERIALS.

Section II

Free-Response Questions

TABLE OF INFORMATION FOR 2008 and 2009

CONSTANTS AND CONVERSION FACTORS

Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	1 electron volt, $1\text{ eV} = 1.60 \times 10^{-19}$ J
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Speed of light, $c = 3.00 \times 10^{8}$ m/s
Avogadro's number, $N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant, $G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg}\cdot\text{s}^2$
Universal gas constant, $R = 8.31$ J/(mol•K)	Acceleration due to gravity at Earth's surface, $g = 9.8\ \text{m/s}^2$
Boltzmann's constant, $k_B = 1.38 \times 10^{-23}$ J/K	

1 unified atomic mass unit,	$1\text{ u} = 1.66 \times 10^{-27}\text{ kg} = 931\ \text{MeV}/c^2$
Planck's constant,	$h = 6.63 \times 10^{-34}\ \text{J}\cdot\text{s} = 4.14 \times 10^{-15}\ \text{eV}\cdot\text{s}$
	$hc = 1.99 \times 10^{-25}\ \text{J}\cdot\text{m} = 1.24 \times 10^{3}\ \text{eV}\cdot\text{nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}\ (\text{T}\cdot\text{m})/\text{A}$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}\ (\text{T}\cdot\text{m})/\text{A}$
1 atmosphere pressure,	$1\text{ atm} = 1.0 \times 10^{5}\ \text{N/m}^2 = 1.0 \times 10^{5}$ Pa

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

PREFIXES

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

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	$1/2$	$3/5$	$\sqrt{2}/2$	$4/5$	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	$4/5$	$\sqrt{2}/2$	$3/5$	$1/2$	0
$\tan\theta$	0	$\sqrt{3}/3$	$3/4$	1	$4/3$	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.

II. The direction of any electric current is the direction of flow of positive charge (conventional current).

III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.

ADVANCED PLACEMENT PHYSICS C EQUATIONS FOR 2008 and 2009

MECHANICS

$$\upsilon = \upsilon_0 + at$$

$$x = x_0 + \upsilon_0 t + \frac{1}{2}at^2$$

$$\upsilon^2 = \upsilon_0^2 + 2a(x - x_0)$$

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

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

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

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

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

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

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

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

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

$$\Delta U_g = mgh$$

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

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

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

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

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

$$\upsilon = r\omega$$

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

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

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

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

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

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

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

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

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

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

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

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

ELECTRICITY AND MAGNETISM

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

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

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

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

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

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

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

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

$$C_p = \sum_i C_i$$

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

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

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

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

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

$$I = Nev_d A$$

$$V = IR$$

$$R_s = \sum_i R_i$$

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

$$P = IV$$

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

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

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

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

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

$$B_s = \mu_0 nI$$

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

$$\mathcal{E} = -\frac{d\phi_m}{dt}$$

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

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

GEOMETRY AND TRIGONOMETRY

Rectangle

$A = bh$

Triangle

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

Circle

$A = \pi r^2$

$C = 2\pi r$

Parallelepiped

$V = \ell wh$

Cylinder

$V = \pi r^2 \ell$

$S = 2\pi r\ell + 2\pi r^2$

Sphere

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

$S = 4\pi r^2$

Right Triangle

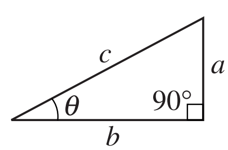
$a^2 + b^2 = c^2$

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

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

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

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



CALCULUS

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

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

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

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

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

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

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

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

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

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

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

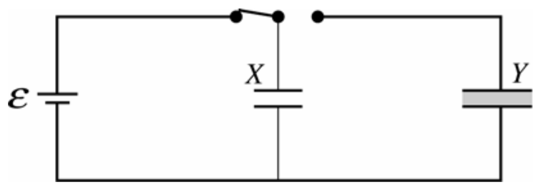
PHYSICS C: ELECTRICITY AND MAGNETISM

SECTION II

Time—45 minutes

3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. All final numerical answers should include appropriate units. Credit depends on the quality of your solutions and explanations, so you should show your work. Credit also depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should clearly indicate which part of a question your work is for.



E&M. 1.

A parallel-plate capacitor X, with plate area A and plate separation d, is filled with air and charged by connecting the capacitor through a switch to a power supply of emf $\mathcal{E}$, as shown above.

(a) Determine the magnitude of the charge q_0 on each plate of the capacitor, in terms of the given quantities and fundamental constants.

The switch is now flipped to the right, so that capacitor X is disconnected from the power supply and is instead connected to an uncharged parallel-plate capacitor Y. Capacitor Y has the same plate separation but twice the plate area and is filled with a material having dielectric constant 3.

(b) Calculate the equilibrium charges q_X and q_Y on capacitors X and Y, expressing your answers in terms of the initial charge q_0.

Once the charges on the two capacitors have reached equilibrium, they are disconnected from one another. The dielectric is then removed from capacitor Y.

(c) Indicate whether the energy stored in capacitor Y as the dielectric is removed increases, decreases or remains the same.

___ Increases ___ Decreases ___ Remains the same

Justify your answer.

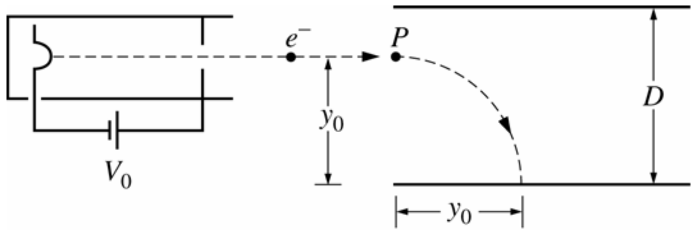
(d) Indicate whether your answer to (c) requires that the electric force on the dielectric as it is removed pulls the dielectric into the capacitor, pushes it out, or is zero.

___ Pulls it in ___ Pushes it out ___ Is zero

Justify your answer.

(e) A resistor of resistance R is now connected to the two sides of capacitor Y. The capacitor is allowed to discharge through the resistor. Derive the equation describing the charge on capacitor Y as a function of time, expressed in terms of R, d, A, the initial charge q_Y on capacitor Y, and fundamental constants.

GO ON TO THE NEXT PAGE.



E&M. 2.

Electrons created at the filament at the left end of the tube represented above are accelerated through a voltage V_0 and exit the tube. The electrons then move with constant speed to the right, as shown, before entering a region in which there is a uniform electric field between two parallel plates separated by a distance D. The electrons enter the field at point P, which is a distance y_0 from the bottom plate, and are deflected toward that plate. Express your answers to the following in terms of V_0, D, y_0, and fundamental constants.

(a) Calculate the speed of the electrons as they exit the tube.

(b) i. Calculate the magnitude of the electric field required to cause the electrons to land the distance y_0 from the edge of the plate.

ii. Indicate the direction of the electric field.

____ To the left	____ To the right
____ Toward the top of the page	____ Toward the bottom of the page
____ Into the page	____ Out of the page

Justify your answer.

(c) Calculate the potential difference between the two plates required to produce the electric field determined in part (b).

Suppose the electric field between the plates is replaced by a magnetic field and the electrons are to strike the lower plate at the same distance y_0 from the edge of the plate.

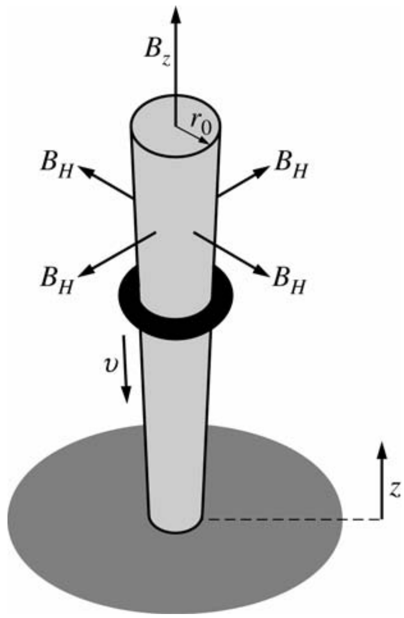
(d) i. Calculate the magnitude of the magnetic field.

ii. Indicate the direction of the required magnetic field.

____ To the left	____ To the right
____ Toward the top of the page	____ Toward the bottom of the page
____ Into the page	____ Out of the page

Justify your answer.

GO ON TO THE NEXT PAGE.



E&M. 3.
An astronaut on another planet erects a tall, thin, vertical, nonconducting, frictionless cylinder of radius r_0 at one of the planet's magnetic poles. Assume the magnetic field has an upward vertical component with a magnitude that varies with altitude z as $B_z = B_0(1 - kz)$, where k is a constant. The horizontal component of the field has the constant value B_H at the surface of the cylinder and points radially outward from the axis of the cylinder. A gold ring of resistance R that just fits around the cylinder is released from rest at some height above the ground. Assume air friction is negligible. Express all algebraic answers in terms of B_0, B_H, k, r_0, R, and fundamental constants.

(a) Determine the magnetic flux through the ring as a function of z.

(b) Indicate whether the direction of the induced current in the ring, as seen from above the cylinder, is clockwise or counterclockwise.

___ Clockwise ___ Counterclockwise

Justify your answer.

(c) Calculate the power dissipated in the ring at the instant it is falling with speed v.

(d) Calculate the magnitude of the net upward force on the ring due to the horizontal component of the field at the instant the ring is falling with speed v.

(e) Is there a net force on the ring due to the vertical component of the field? Explain your reasoning.

STOP

END OF EXAM

Name: ______________________________

AP® Physics C: Electricity and Magnetism
Student Answer Sheet for Multiple-Choice Section

No.	Answer
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	
23	
24	
25	
26	
27	
28	
29	
30	

No.	Answer
31	
32	
33	
34	
35	

AP® Physics C: Electricity and Magnetism
Multiple-Choice Answer Key

No.	Correct Answer
1	D
2	D
3	C
4	A
5	E
6	C
7	C
8	B
9	D
10	A
11	C
12	B
13	C
14	E
15	D
16	B
17	B
18	B
19	A
20	E
21	C
22	B
23	C
24	C
25	A
26	D
27	A
28	B
29	C
30	A

No.	Correct Answer
31	C
32	C
33	E
34	C
35	E

AP® Physics C: Electricity and Magnetism
Free-Response Scoring Guidelines

General Notes about AP Physics Practice Exam Scoring Guidelines

1. The solutions contain a common method of solving the free-response questions and the allocation of points for the solutions. Some also contain a common alternate solution. They are typical of draft guidelines developed before student solutions are available. Teachers should feel free to make modifications based on their students' responses.

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

The following rules apply to the official scoring of AP Physics Exams.

3. All correct methods of solution receive appropriate credit for correct work.

4. 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.

5. Implicit statements of concepts normally receive credit. For example, if use of the 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 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 Course Description*.

6. 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.

Question 1

15 points total | **Distribution of points**

(a) 2 points

For using the expressions relating charge to emf and capacitance to capacitor dimensions — 1 point

$q_0 = C\mathcal{E}$

$C = \dfrac{\epsilon_0 A}{d}$

For the correct answer — 1 point

$q_0 = \dfrac{\epsilon_0 A}{d}\mathcal{E}$

(b) 5 points

For correct use of conservation of charge — 1 point

$q_X + q_Y = q_0$

For indicating that at equilibrium the voltage is the same across each capacitor — 1 point

$V_X = V_Y = \dfrac{q_X}{C_X} = \dfrac{q_Y}{C_Y}$

For a correct relationship between C_X and C_Y — 1 point

$C_Y = \dfrac{3\epsilon_0(2A)}{d} = \dfrac{6\epsilon_0 A}{d} = 6C_X$

Combining these relationships to solve for q_X

$\dfrac{q_X}{C_X} = \dfrac{q_0 - q_X}{6C_X}$

$6q_X = (q_0 - q_X)$

For correct answers for both capacitors — 2 points

$q_X = \dfrac{1}{7}q_0$

$q_Y = \dfrac{6}{7}q_0$

Note: 1 point partial credit will be given if the correct charge for only one of the capacitors is given.

Question 1 (continued)

		Distribution of points
(c)	2 points	
	For correctly indicating that the stored energy increases as the dielectric is removed	1 point
	For a valid justification	1 point
	For example: Removing the dielectric will decrease the capacitance of capacitor Y by a factor of 3. The charge on the capacitor stays the same. So the stored energy $U = q^2/2C$ will increase by a factor of 3.	
(d)	3 points	
	For correctly indicating that the dielectric will be pulled in	1 point
	For a valid justification	2 points
	For example: Removing the dielectric increases the stored energy. This means that positive work was done on the system to remove it. This requires an external force to pull the dielectric material out, acting opposite to the electric force. So the electric force pulls the dielectric in.	
	<u>Note</u>: *Full credit can be given if correct reasoning is used, even if an incorrect conclusion is reached based on an incorrect answer in part (c).*	
(e)	3 points	
	For a correct expression of the voltage loop equation for the circuit	1 point
	$\frac{q}{C_Y} = IR$	
	$\frac{q}{C_Y} = -\frac{dq}{dt}R$	
	A general form for the solution of this equation can be determined by integration or deduced by inspection.	
	For giving the proper exponential form of the solution	1 point
	$q(t) = q_i\ e^{-t/RC}$	
	Using the initial condition at $t = 0$	
	$q(0) = q_i = q_Y$	
	For the correct answer	1 point
	$q(t) = q_Y\ e^{-td/2\epsilon_0 RA}$	

AP® Physics C: Electricity and Magnetism
Free-Response Scoring Guidelines

Question 2

15 points total | **Distribution of points**

(a) 2 points

For correct application of conservation of energy — 1 point

$$\frac{1}{2}m_e\upsilon^2 = eV_0$$

For the correct answer — 1 point

$$\upsilon = \sqrt{\frac{2eV_0}{m_e}}$$

(b)

(i) 4 points

For a correct application of the kinematic equation and Newton's second law in the vertical direction — 1 point

$$\Delta y = \frac{1}{2}at^2 \quad \text{where } \Delta y = y_0, \quad a = \frac{eE}{m_e}$$

Combining these equations and solving for t

$$y_0 = \frac{1}{2}\frac{eE}{m_e}t^2$$

$$t = \sqrt{2y_0m_e/eE}$$

For a correct application of the kinematic equation in the horizontal direction — 1 point

$$\Delta x = \upsilon_{0x}t \quad \text{where } \Delta x = y_0$$

For indicating that υ_{0x} is the answer from part (a) — 1 point

$$y_0 = \sqrt{\frac{2eV_0}{m_e}}\sqrt{\frac{2y_0m_e}{eE}}$$

For the correct answer — 1 point

$$E = \frac{4V_0}{y_0}$$

(ii) 2 points

For correctly indicating that the electric field is directed toward the top of the page — 1 point

For a correct justification — 1 point

For example: Negative charges are accelerated in the direction opposite the electric field. Since the acceleration here is downward, the field must be upward.

Question 2 (continued)

Distribution of points

(c) 1 point

$V = Ed$

For the correct answer — 1 point

$$V = \frac{4V_0 D}{y_0}$$

(d)

(i) 4 points

For equating the magnetic force to the centripetal force — 2 points

$$e\upsilon B = \frac{m_e \upsilon^2}{y_0}$$

$$B = \frac{m_e \upsilon}{e y_0}$$

For using the result for υ from part (a) — 1 point

$$B = \frac{m_e}{e y_0}\sqrt{\frac{2eV_0}{m_e}}$$

For the correct answer — 1 point

$$B = \sqrt{\frac{2 m_e V_0}{e y_0^2}}$$

(ii) 2 points

For correctly indicating that the magnetic field must be directed into the page — 1 point

For a correct justification — 1 point

For example: Using the right-hand rule, a field out of the page would produce an initial downward force on positively charged particles. Since these are electrons, the field must be in the opposite direction.

Question 3

15 points total | **Distribution of points**

(a) 2 points

$\phi_m = B_z A$

For using the correct area — 1 point

$A = \pi r_0^2$

For the correct answer — 1 point

$\phi_m = B_0(1 - kz)\pi r_0^2$

(b) 3 points

For correctly indicating that the current is clockwise — 1 point

For a correct justification — 2 points

For example: The vertical component of the magnetic field and thus the flux is increasing with time because the magnetic field increases with decreasing *z*. The induced current will act to oppose the change in flux and create a downward field.

<u>Note</u>: 1 point partial credit can be earned for stating just one of the two ideas above.

(c) 5 points

For indicating the need to take the derivative of the flux to calculate the induced emf — 1 point

For correctly taking the derivative — 1 point

$$\varepsilon = -\frac{d\phi_m}{dt} = \pi r_0^2 B_0 k \frac{dz}{dt}$$

For correctly equating $\frac{dz}{dt}$ with the velocity υ — 1 point

$$\varepsilon = -\frac{d\phi_m}{dt} = \pi r_0^2 B_0 k \upsilon$$

For applying a valid power equation — 1 point

$$P = \frac{\varepsilon^2}{R}$$

For the correct answer — 1 point

$$P = \frac{\pi^2 r_0^4 B_0^2 k^2 \upsilon^2}{R}$$

Question 3 (continued)

Distribution of points

(d) 3 points

$F = I\ell B_{radial}$

For the correct determination of the path length ℓ — 1 point

$\ell = 2\pi r_0$

For the correct substitution of the current I — 1 point

$$I = \frac{\varepsilon}{R} = \pi r_0^2 \frac{B_0 k \upsilon}{R}$$

$$F = \pi r_0^2 \frac{B_0 k \upsilon}{R}(2\pi r_0)B_H$$

For the correct answer — 1 point

$$F = 2\pi^2 r_0^3 \frac{kB_0 B_H \upsilon}{R}$$

(e) 2 points

For correctly indicating that there is no net force due to the vertical component of the magnetic field — 1 point

For a correct justification — 1 point

For example: For any pair of points on the ring located opposite each other, there are equal but opposite forces acting on the ring that cancel.