Electricity and Magnetism Practice Exam for AP Physics C

by Greg Jacobs Joshua Schulman,

Below is a electricity and magnetism practice exam for AP Physics C exam. There are two sections in this practice exam. Section I has 35 multiple choice questions. Section II has 3 free response questions. For a thorough review of the concepts in this practice exam, refer to the information center on AP Physics Notes.

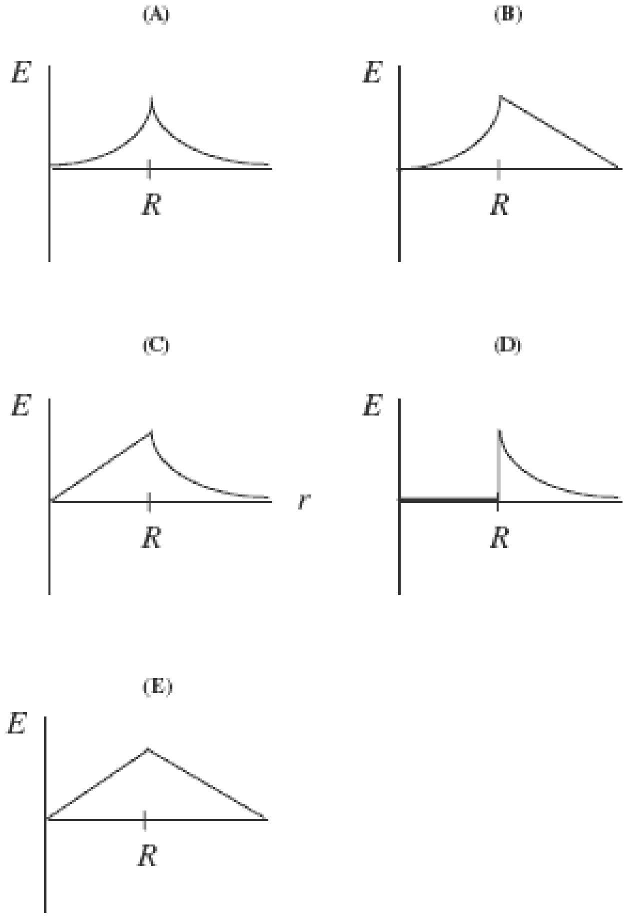
If you are taking both AP Physics C exams, the mechanics practice exam can be found at: Mechanics Practice Exam for AP Physics C

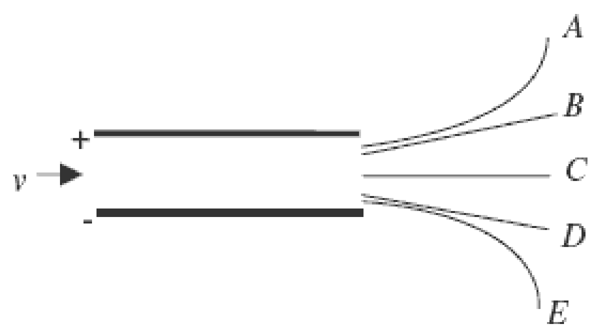
Problems

Multiple Choice Questions

Time: 45 minutes. You may refer to the Constants sheet. However, you may not use the Equations sheet, and you may not use a calculator on this portion of the exam.

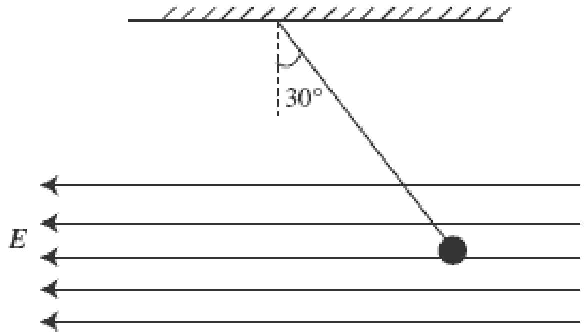
1. Experimenter A uses a very small test charge q_o, and experimenter *B* uses a test charge $2q_o$ to measure an electric field produced by two parallel plates. *A* finds a field that is
   A. greater than the field found by *B*
   B. the same as the field found by *B*
   C. less than the field found by *B*
   D. either greater or less than the field found by *B*, depending on the accelerations of the test charges
   E. either greater or less than the field found by *B*, depending on the masses of the test charges
2. A solid conducting sphere has radius *R* and carries positive charge *Q*. Which of the following graphs represents the electric field *E* as a function of the distance *r* from the center of the sphere?





3. An electron moving at constant velocity enters the region between two charged plates, as shown above. Which of the paths above correctly shows the electron's trajectory after leaving the region between the charged plates?
   A. *A*
   B. *B*
   C. *C*
   D. *D*
   E. *E*
4. Two isolated particles, *A* and *B*, are 4 m apart. Particle *A* has a net charge of 2*Q*, and *B* has a net charge of *Q*. The ratio of the magnitude of the electric force on *A* to that on B is
   A. 4:1
   B. 2:1
   C. 1:1

D. 1:2
E. 1:4



5. A uniform electric field points to the left. A small metal ball charged to –2 mC hangs at a 30° angle from a string of negligible mass, as shown above. The tension in the string is measured to be 0.1 N. What is the magnitude of the electric field? (sin 30° = 0.50; cos 30° = 0.87; tan 30° = 0.58).
   A. 25 N/C
   B. 50 N/C
   C. 2500 N/C
   D. 5000 N/C
   E. 10,000 N/C

6. A thin semicircular conductor of radius *R* holds charge +*Q*. What is the magnitude and direction of the electric field at the center of the circle?

   (A) $\frac{kQ}{R^2}$, ↑

   (B) $\frac{kQ}{R^2}$, ↓

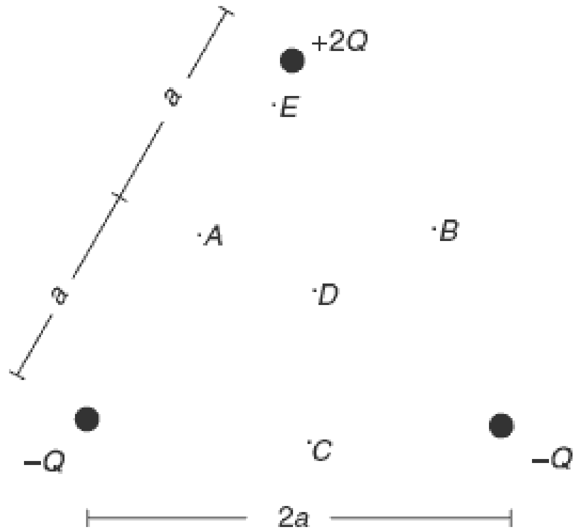
   (C) $\frac{kQ}{\pi R^2}$, ↑

   (D) $\frac{kQ}{\pi R^2}$, ↓

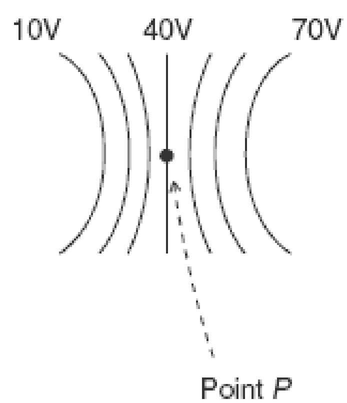
   (E) The electric field is zero at the center.

7. Above an infinitely large plane carrying charge density σ, the electric field points up and is equal to $\sigma/2\varepsilon_o$. What is the magnitude and direction of the electric field below the plane?
   A. $\sigma/2\varepsilon_o$, down

B. $\sigma/2\varepsilon_o$, up
C. σ/ε_o, down
D. σ/ε_o, up
E. zero



8. Three charges are arranged in an equilateral triangle, as shown above. At which of these points is the electric potential smallest?
   A. *A*
   B. *B*
   C. *C*
   D. *D*
   E. *E*



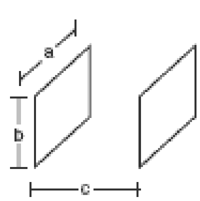
9. The diagram shows a set of equipotential surfaces. At point *P*, what is the direction of the electric field?
   A. left
   B. right
   C. up the page
   D. down the page
   E. either left or right, which one cannot be determined

10. A metal sphere carries charge *Q*; a nonconducting sphere of equal size carries the same charge *Q*, uniformly distributed throughout the sphere. These spheres are isolated from each other. Consider the electric field at the center of the spheres, within the spheres, and outside the spheres. Which of these electric fields will be the same for both spheres, and which will be different?

	At the Center	Elsewhere Within the Sphere	Outside the Sphere
(A)	Same	Same	Same
(B)	Same	Same	Different
(C)	Same	Different	Same
(D)	Different	Different	Same
(E)	Different	Different	Different

11. Under what conditions is the net electric flux through a closed surface proportional to the enclosed charge?
    A. under any conditions
    B. only when the enclosed charge is symmetrically distributed
    C. only when all nearby charges are symmetrically distributed
    D. only when there are no charges outside the surface
    E. only when enclosed charges can be considered to be point charges

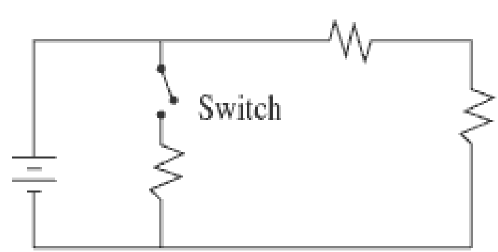
12. A hollow metal ring of radius *r* carries charge *q*. Consider an axis straight through the center of the ring. At what point(s) along this axis is/are the electric field equal to zero?
    A. only at the center of the ring
    B. only at the center of the ring, and a very long distance away
    C. only a very long distance away
    D. only at the center of the ring, a distance *r* away from the center, and a very long distance away
    E. everywhere along this axis



13. A parallel plate capacitor consists of identical rectangular plates of dimensions $a \times b$, separated by a distance *c*. To cut the capacitance of this capacitor in half, which of these quantities should be doubled?
    A. *a*
    B. *b*

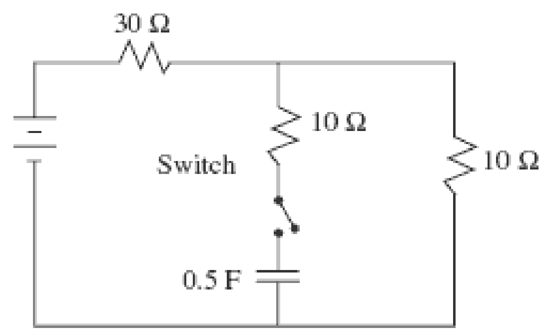
C. *c*
D. *ab*
E. *abc*

14. Two identical capacitors are hooked in parallel to an external circuit. Which of the following quantities must be the same for both capacitors?
    I. the charge stored on the capacitor
    II. the voltage across the capacitor
    III. the capacitance of the capacitor
    A. I only
    B. II only
    C. II and III only
    D. I and III only
    E. I, II, and III
15. A 2-μF capacitor is connected directly to a battery. When the capacitor is fully charged, it stores 600 μC of charge. An experimenter replaces the 2-μF capacitor with three 18-μF capacitors in series connected to the same battery. Once the capacitors are fully charged, what charge is stored on each capacitor?
    A. 100 μC
    B. 200 μC
    C. 600 μC
    D. 1200 μC
    E. 1800 μC
16. A spherical conductor carries a net charge. How is this charge distributed on the sphere?
    A. The charge is evenly distributed on the surface.
    B. The charge resides on the surface only; the distribution of charge on the surface depends on what other charged objects are near the sphere.
    C. The charge moves continually within the sphere.
    D. The charge is distributed uniformly throughout the sphere.
    E. The charge resides within the sphere; the distribution of charge within the sphere depends on what other charged objects are near the sphere.

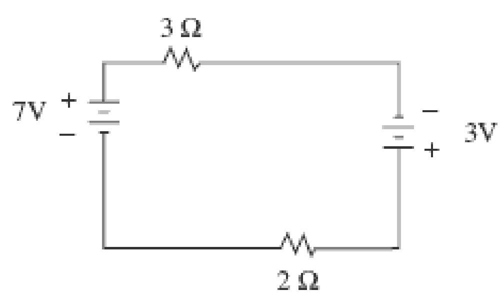


17. Three resistors are connected to a battery as shown in the diagram above. The switch is initially open. When the switch is closed, what happens to the total voltage, current, and resistance in the circuit?

	Voltage	Current	Resistance
(A)	increases	increases	increases
(B)	does not change	does not change	does not change
(C)	does not change	decreases	increases
(D)	does not change	increases	decreases
(E)	decreases	decreases	decreases

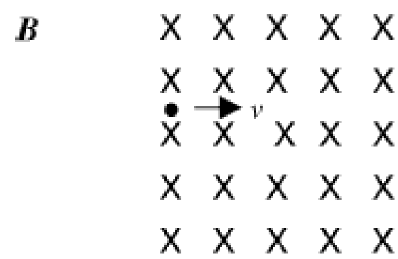


18. In the circuit shown above, the 0.5 F capacitor is initially uncharged. The switch is closed at time *t* = 0. What is the time constant (the time for the capacitor to charge to 63% of its maximum charge) for the charging of this capacitor?
    A. 5 s
    B. 10 s
    C. 20 s
    D. 30 s
    E. 40 s

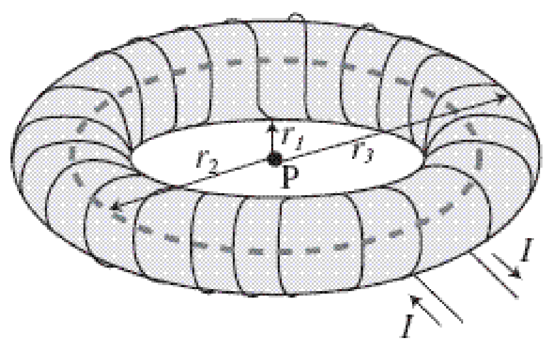


19. In the circuit shown above, what is the current through the 3 Ω resistor?
    A. 0 A
    B. 0.5 A
    C. 1.0 A
    D. 1.5 A
    E. 2.0 A
20. A light bulb rated at 100 W is twice as bright as a bulb rated at 50 W when both are connected in parallel directly to a 100-V source. Now imagine that these bulbs are instead connected in series with each other. Which is brighter, and by how much?
    A. The bulbs have the same brightness.

B. The 100-W bulb is twice as bright.
C. The 50-W bulb is twice as bright.
D. The 100-W bulb is four times as bright.
E. The 50-W bulb is four times as bright.



21. A uniform magnetic field *B* is directed into the page. An electron enters this field with initial velocity *v* to the right. Which of the following best describes the path of the electron while it is still within the magnetic field?
    A. It moves in a straight line.
    B. It bends upward in a parabolic path.
    C. It bends downward in a parabolic path.
    D. It bends upward in a circular path.
    E. It bends downward in a circular path.



22. Wire is wound around an insulated circular donut, as shown above. A current I flows in the wire in the direction indicated by the arrows. The inner, average, and outer radii of the donut are indicated by r_1, r_2, and r_3, respectively. What is the magnitude and direction of the magnetic field at point P, the center of the donut?

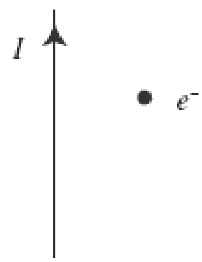
(A) zero

(B) $\frac{\mu_o I}{2r_1}$

(C) $\frac{\mu_o I}{2r_2}$

(D) $\frac{\mu_o I}{2r_3}$

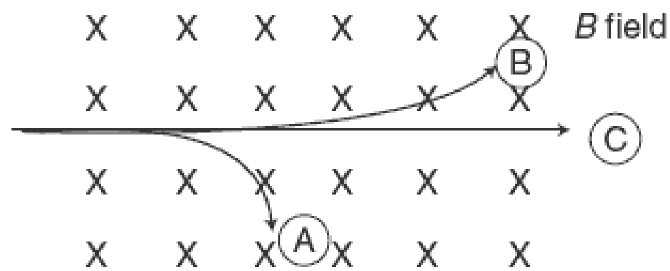
(E) $\frac{\mu_o I}{2\pi r_2}$



23. A wire carries a current toward the top of the page. An electron is located to the right of the wire, as shown above. In which direction should the electron be moving if it is to experience a magnetic force toward the wire?
    A. into the page
    B. out of the page
    C. toward the bottom of the page
    D. toward the top of the page
    E. to the right
24. Which of the following statements about electric and magnetic fields is FALSE:
    A. A charge moving along the direction of an electric field will experience a force, but a charge moving along the direction of a magnetic field will not experience a force.
    B. All charges experience a force in an electric field, but only moving charges can experience a force in a magnetic field.
    C. A positive charge moves in the direction of an electric field; a positive charge moves perpendicular to a magnetic field.
    D. All moving charges experience a force parallel to an electric field and perpendicular to a magnetic field.
    E. A negative charge experiences a force opposite the direction of an electric field; a negative charge experiences a force perpendicular to a magnetic field.
25. Which of these quantities decreases as the inverse square of distance for distances far from the objects producing the fields?
    A. the electric field produced by a finite-length charged rod
    B. the electric field produced by an infinitely long charged cylinder

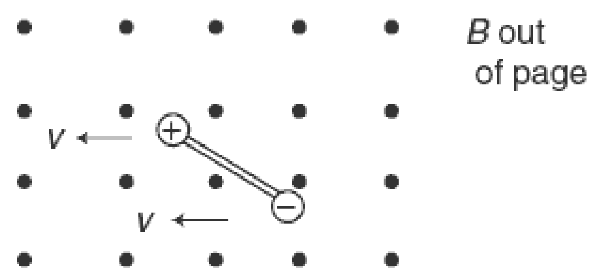
C. the electric field produced by an infinite plane of charge
D. the magnetic field produced by an infinitely long straight current carrying wire
E. the magnetic field produced by a wire curled around a torus

26. A proton enters a solenoid. Upon entry, the proton is moving in a straight line along the axis of the solenoid. Which of the following is a correct description of the proton's motion within the solenoid?
A. The proton will be bent in a parabolic path.
B. The proton will be bent in a circular path.
C. The proton will continue in its straight path at constant velocity.
D. The proton will continue in its straight path and slow down.
E. The proton will continue in its straight path and speed up.



27. A uniform magnetic field points into the page. Three subatomic particles are shot into the field from the left-hand side of the page. All have the same initial speed and direction. These particles take paths A, B, and C, as labeled in the diagram above. Which of the following is a possible identity for each particle?

	A	B	C
(A)	antiproton	proton	electron
(B)	antiproton	positron	neutron
(C)	proton	electron	neutron
(D)	positron	antiproton	neutron
(E)	electron	proton	neutron

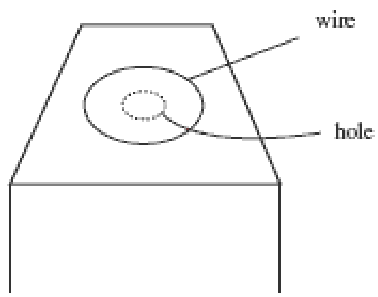


28. The electric dipole shown above consists of equal-magnitude charges and has an initial leftward velocity v in a uniform magnetic field pointing out of the page, as shown above. The dipole experiences
A. a clockwise net torque, and a net force to the left
B. a counterclockwise net torque, and a net force to the left
C. no net torque, and a net force to the left

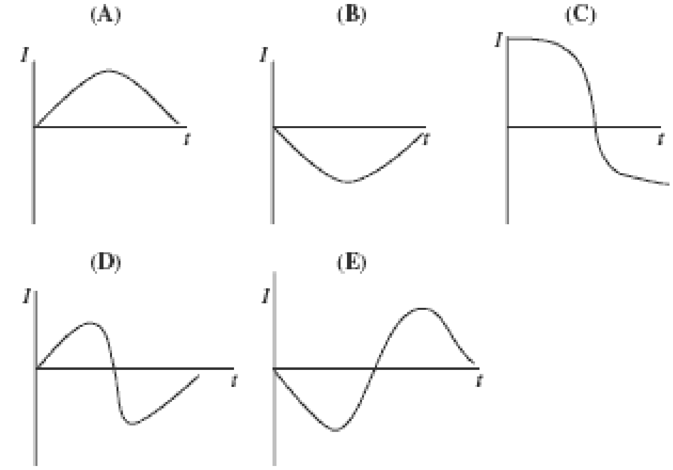
D. a counterclockwise net torque, and no net force
E. a clockwise net torque, and no net force

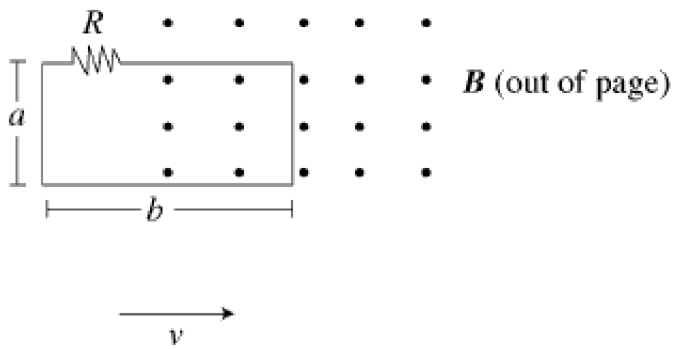
29. A beam of electrons has speed 10^7 m/s. It is desired to use the magnetic field of the Earth, 5×10^{-5} T, to bend the electron beam into a circle. What will be the radius of this circle?
A. 1 nm
B. 1 μm
C. 1 mm
D. 1 m
E. 1 km

30. A very small element of wire of length d*L* carries a current *I*. What is the direction of the magnetic field produced by this current element at point *P*, shown above?
A. to the right
B. toward the top of the page
C. into the page
D. out of the page
E. there is no magnetic field produced at point *P* by this element.

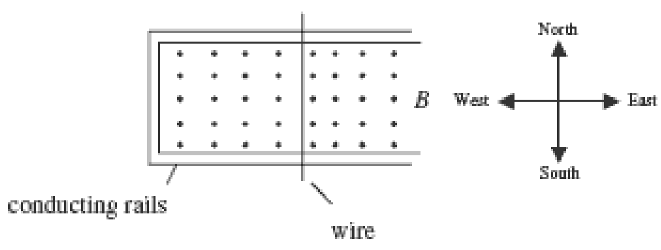


31. A loop of wire surrounds a hole in a table, as shown above. A bar magnet is dropped, north end down, from far above the table through the hole. Let the positive direction of current be defined as counterclockwise as viewed from above. Which of the following graphs best represents the induced current *I* in the loop?



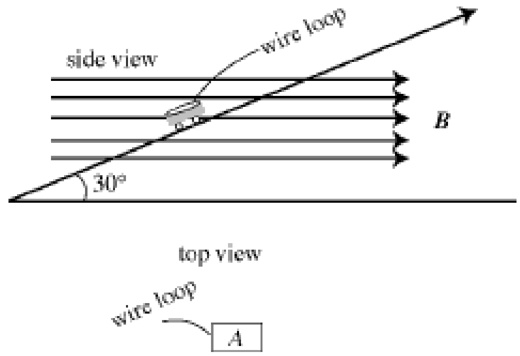


32. A rectangular loop of wire has dimensions *a* × *b*and includes a resistor *R*. This loop is pulled with speed *v* from a region of no magnetic field into a uniform magnetic field *B* pointing through the loop, as shown above. What is the magnitude and direction of the current through the resistor?
    A. *Bav*/*R*, left-to-right
    B. *Bbv*/*R*, left-to-right
    C. *Bav*/*R*, right-to-left
    D. *Bbv*/*R*, right-to-left
    E. *Bba*/*R*, right-to-left

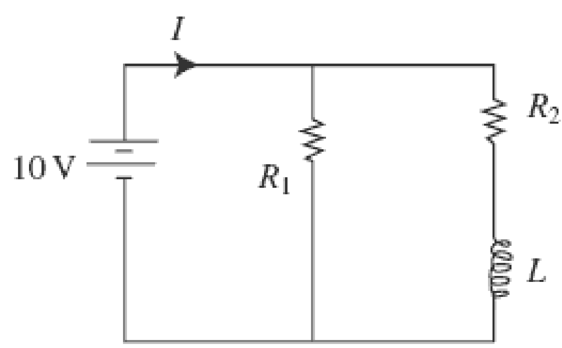


33. A conducting wire sits on smooth metal rails, as shown above. A variable magnetic field points out of the page. The strength of this magnetic field is increased linearly from zero. Immediately after the field starts to increase, what will be the direction of the current in the wire and the direction of the wire's motion?

	Current in the Wire	Motion of the Wire
(A)	north	no motion
(B)	north	east
(C)	north	west
(D)	south	west
(E)	south	east



34. A uniform magnetic field *B* points parallel to the ground. A toy car is sliding down a frictionless plane inclined at 30°. A loop of wire of resistance *R* and cross-sectional area *A* lies in the flat plane of the car's body, as shown above. What is the magnetic flux through the wire loop?
    A. zero
    B. *BA* cos 30°
    C. *BA* cos 60°
    D. *BA*
    E. (*BA* cos 60°)/*R*



35. If the two equal resistors R_1 and R_2 are connected in parallel to a 10-V battery with no other circuit components, the current provided by the battery is *I*. In the circuit shown above, an inductor of inductance *L* is included in series with R_2. What is the current through R_2 after the circuit has been connected for a long time?
    A. zero
    B. (1/4) *I*
    C. (1/2) *I*
    D. *I*

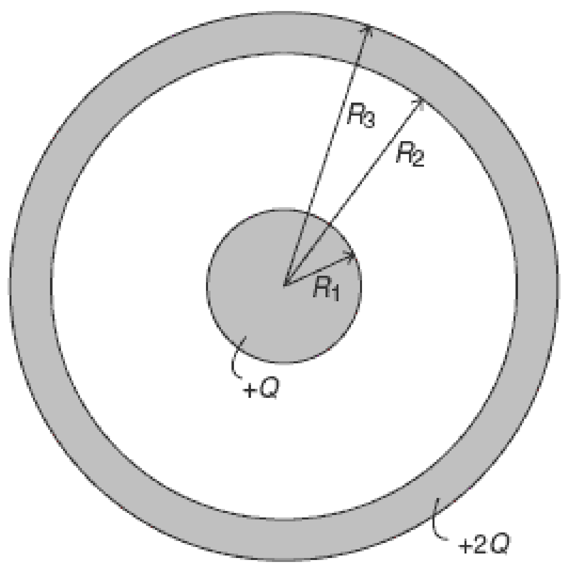
E. $I\frac{R_1+R_2}{LR_2}$

STOP. End of Physics C—Electricity and Magnetism Practice Exam—Multiple-Choice Questions

Free-Response Questions

Time: 45 minutes. You may refer to the Constants sheet and Equations sheet. You may also use a calculator on this portion of the exam.

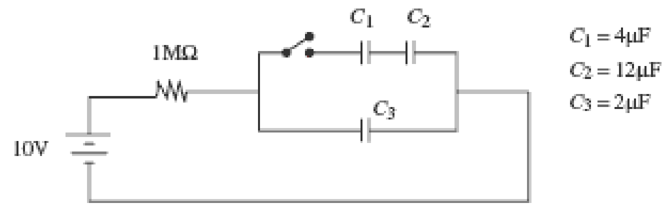
E&M 1



A metal sphere of radius R_1 carries charge +Q. A concentric spherical metal shell, of inner radius R_2 and outer radius R_3, carries charge +2Q.

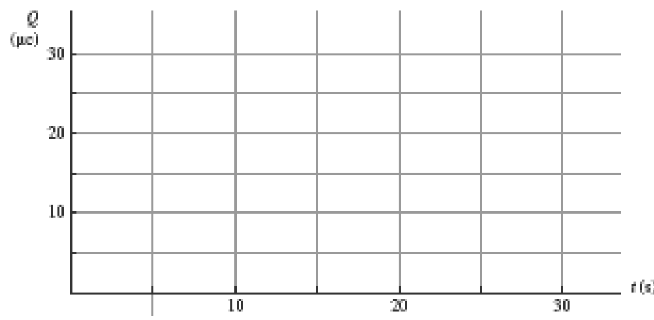
a. Let r represent the distance from the center of the spheres. Calculate the electric field as a function of r in each of the following four regions:
   1. between r = 0 and $r = R_1$
   2. between $r = R_1$ and $r = R_2$
   3. between $r = R_2$ and $r = R_3$
   4. between $r = R_3$ and r = O
b. How much charge is on each surface of the outer spherical shell? Justify your answer.
c. Determine the electric potential of the outer spherical shell.
d. Determine the electric potential of the inner metal sphere.

E&M 2



A 1 MΩ resistor is connected to the network of capacitors shown above. The circuit is hooked to a 10-V battery. The capacitors are initially uncharged. The battery is connected and the switch is closed at time t = 0.

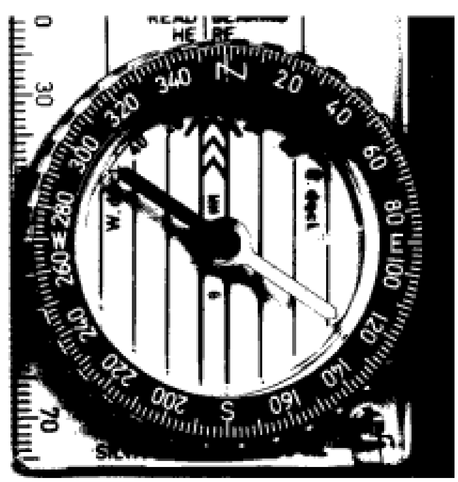
a. Determine the equivalent capacitance of C_1, C_2, and C_3.
b. Determine the charge on and voltage across each capacitor after a long time has elapsed.
c. On the axes below, sketch the total charge on C_3 as a function of time.



d. After the capacitors have been fully charged, the switch is opened, disconnecting C_1 and C_2 from the circuit. What happens to the voltage across and charge on C_3? Justify your answer.

E&M 3

In the laboratory, far from the influence of other magnetic fields, the Earth's magnetic field has a value of 5.00×10^{-5} T. A compass in this lab reads due north when pointing along the direction of Earth's magnetic field.



A long, straight current-carrying wire is brought close to the compass, deflecting the compass to the position shown above, 48° west of north.

a. Describe one possible orientation of the wire and the current it carries that would produce the deflection shown.
b. Calculate the magnitude B_{wire} of the magnetic field produced by the wire that would cause the deflection shown.
c. The distance d from the wire to the compass is varied, while the current in the wire is kept constant; a graph of B_{wire} vs. d is produced. On the axes below, sketch the shape of this graph.

d. It is desired to adjust this plot so that the graph becomes a straight line. The vertical axis is to remain B_{wire}, the magnetic field produced by the wire. How could the quantity graphed on the horizontal axis be adjusted to produce a straight line graph? Justify your answer.
e. The current carried by the wire is 500 mA. Determine the slope of the line on the graph suggested in part (d).

STOP. End of Physics C—Electricity and Magnetism Practice Exam—Free-Response Questions

Solutions

Multiple-Choice Solutions

1. **B**—An electric field exists regardless of the amount of charge placed in it, and regardless of whether any charge at all is placed in it. So both experimenters must measure the same field (though they will measure different forces on their test charges).
2. **D**—You could use Gauss's law to show that the field outside the sphere has to decrease as 1/r 2, eliminating choices B and E. But it's easier just to remember that an important result of Gauss's law is that the *electric field inside a conductor is always zero everywhere*, so D is the only possibility.
3. **B**—While in the region between the plates, the negatively charged electron is attracted to the positive plate, so bends upward. But after leaving the plates, there is no more force acting on the electron. Thus, the electron continues in motion in a straight line by Newton's first law.
4. **C**—This is a Newton's third law problem! The force of *A* on *B* is equal (and opposite) to the force of

B on *A*. Or, we can use Coulomb's law: The field due to *A* is $k(2Q)/(4\text{ m})^2$. The force on *B* is $QE = k2QQ/(4\text{ m})^2$. We can do the same analysis finding the field due to *B* and the force on *A* to get the same result.

5. **A**—The charge is in equilibrium, so the horizontal component of the tension must equal the electric force. This horizontal tension is 0.1 N times sin 30° (not cosine because 30° was measured from the *vertical*), or 0.05 N. The electric force is qE, where q is 0.002 C. So the electric field is 0.050 N/0.002 C. Reduce the expression by moving the decimal to get 50/2, or 25 N/C.
6. **D**—The answer could, in principle, be found using the integral form of Coulomb's law. But you can't do that on a one-minute multiple-choice problem. The electric field will point down the page—the field due to a positive charge points away from the charge, and there's an equal amount of charge producing a rightward field as a leftward field, so horizontal fields cancel. So, is the answer B or D? Choice B is not correct because electric fields add as vectors. Only the vertical component of the field due to each little charge element contributes to the net electric field, so the net field must be *less than* kQ/R^2.
7. **A**—Use the symmetry of the situation to see the answer. Because the infinitely large plane looks the same on the up side as the down side, its electric field must look the same, too—the field must point away from the plane and have the same value.
8. **C**—Another way to look at this question is, "where would a small positive charge end up if released near these charges?" because positive charges seek the smallest potential. The positive charge would be repelled by the +2*Q* charge and attracted to the –*Q* charges, so would end up at point *C*. Or, know that potential due to a point charge is kq/r. Point *C* is closest to both –*Q* charges, so the *r* terms will be smallest, and the negative contribution to the potential will be largest; point *C* is farthest from the +2*Q* charge, so the *r* term will be large, and the positive contribution to the potential will be smallest.
9. **A**—A positive charge is forced from high to low potential, which is generally to the left; and the force on a positive charge is in the direction of the electric field. At point P itself the electric field is directly to the left because an electric field is always perpendicular to equipotential surfaces.
10. **C**—The charge on the metal sphere distributes uniformly on its surface. Because the non-conducting sphere also has a uniform charge distribution, by symmetry the electric fields will cancel to zero at the center. Outside the spheres we can use Gauss's law: $E \cdot A = Q_{enclosed}/\varepsilon_o$. Because the charge enclosed by a Gaussian surface outside either sphere will be the same, and the spheres are the same size, the electric field will be the same everywhere outside either sphere. But within the sphere? A Gaussian surface drawn inside the conducting sphere encloses no charge, while a Gaussian surface inside the non-conducting sphere does enclose some charge. The fields inside must *not* be equal.
11. **A**—That's what Gauss's law says: Net flux through a closed surface is equal to the charge enclosed divided by ε_o. Though Gauss's law is only *useful* when all charge within or without a Gaussian surface is symmetrically distributed, Gauss's law is *valid* always.
12. **B**—The electric field at the center of the ring is zero because the field caused by any charge element is canceled by the field due to the charge on the other side of the ring. The electric field decreases as $1/r^2$ by Coulomb's law, so a long distance away from the ring the field goes to zero. The field is nonzero near the ring, though, because each charge element creates a field pointing away from the ring, resulting in a field always along the axis.

13. **C**—Capacitance of a parallel plate capacitor is $\varepsilon_o A/d$, where *A* is the area of the plates, and *d* is the separation between plates. To halve the capacitance, we must halve the area or double the plate separation. The plate separation in the diagram is labeled *c*, so double distance *c*.
14. **E**—We are told that the capacitors are identical, so their capacitances must be equal. They are hooked in parallel, meaning the voltages across them must be equal as well. By $Q = CV$, the charge stored by each must also be equal.
15. **E**—First determine the voltage of the battery by $Q = CV$. This gives V = 600 μC/2 μF = 300 V. This voltage is hooked to the three series capacitors, whose equivalent capacitance is 6 μF (series capacitors add inversely, like parallel resistors). So the total charge stored now is (6 μF)(300 V) = 1800 μC. This charge is *not* split evenly among the capacitors, though! Just as the current through series resistors is the same through each and equal to the total current through the circuit, the charge on series capacitors is the same and equal to the total.
16. **B**—The charge does reside on the surface, and, if the conductor is alone, will distribute evenly. But, if there's another nearby charge, then this charge can repel or attract the charge on the sphere, causing a redistribution.
17. **D**—The voltage must stay the same because the battery by definition provides a constant voltage. Closing the switch adds a parallel branch to the network of resistors. Adding a parallel resistor *reduces* the total resistance. By Ohm's law, if voltage stays the same and resistance decreases, total current must increase.
18. **C**—The time constant for an RC circuit is equal to RC. The resistance used is the resistance encountered by charge that's flowing to the capacitor; in this case, 40 Ω. So RC = 20 s.
19. **E**—Assume that the current runs clockwise in the circuit, and use Kirchoff 's loop rule. Start with the 7-V battery and trace the circuit with the current: + 7V – I(3Ω) + 3V – I(2Ω) = 0. Solve for I to get 2.0 A.
20. **C**—The intrinsic property of the light bulb is *resistance*; the power dissipated by a bulb depends on its voltage and current. When the bulbs are connected to the 100-V source, we can use the expression for power $P = V^2/R$ to see that the bulb rated at 50 watts has twice the resistance of the other bulb. Now in series, the bulbs carry the same current. Power is also I^2R; thus the 50-watt bulb with twice the resistance dissipates twice the power, and is twice as bright.
21. **E**—The electron bends downward by the right-hand rule for a charge in a B field—point to the right, curl fingers into the page, and the thumb points up the page. But the electron's negative charge changes the force to down the page. The path is a circle because the direction of the force continually changes, always pointing perpendicular to the electron's velocity. Thus, the force on the electron is a centripetal force.
22. **A**—This is one of the important consequences of Ampére's law. The magnetic field inside the donut is always along the axis of the donut, so the symmetry demands of Ampére's law are met. If we draw an "Ampérean Loop" around point *P* but inside r_1, this loop encloses no current; thus the magnetic field must be zero.
23. **C**—The magnetic field due to the wire at the position of the electron is into the page. Now use the other right-hand rule, the one for the force on a charged particle in a magnetic field. If the charge moves down the page, then the force on a positive charge would be to the right, but the force on a (negative) electron would be left, toward the wire.
24. **C**—A positive charge experiences a force in the direction of an electric field, and perpendicular to a

magnetic field; but the direction of a force is not necessarily the direction of motion.

25. **A**—The electric field due to *any* finite-sized charge distribution drops off as $1/r^2$ a long distance away because if you go far enough away, the charge looks like a point charge. This is not true for infinite charge distributions, though. The magnetic field due to an infinitely long wire is given by

    not proportional to $1/r^2$; the magnetic field produced by a wire around a torus is zero outside the torus by Ampére's law.

26. **C**—The magnetic field produced by a single loop of wire at the center of the loop is directly out of the loop. A solenoid is a conglomeration of many loops in a row, producing a magnetic field that is uniform and along the axis of the solenoid. So, the proton will be traveling parallel to the magnetic field. By $F = qvB \sin\theta$, the angle between the field and the velocity is zero, producing no force on the proton. The proton continues its straight-line motion by Newton's first law.
27. **E**—By the right-hand rule for the force on a charged particle in a magnetic field, particle C must be neutral, particle B must be positively charged, and particle A must be negatively charged. Charge B must be more massive than charge A because it resists the change in its motion more than A. A proton is positively charged and more massive than the electron; the neutron is not charged.
28. **E**—The force on the positive charge is upward; the force on the negative charge is downward. These forces will tend to rotate the dipole clockwise, so only A or E could be right. Because the charges and velocities are equal, the magnetic force on each = qvB and is the same. So, there is no net force on the dipole. (Yes, no net force, even though it continues to move to the left.)
29. **D**—The centripetal force keeping the electrons in a circle is provided by the magnetic force. So set $qvB = mv^2/r$. Solve to get $r = (mv)/(qB)$. Just look at orders of magnitude now: $r = (10^{-31}\text{ kg})(10^7\text{m/s})/(10^{-19}\text{ C})(10^{-5}\text{ T})$. This gives $r = 10^{24}/10^{24} = 10^0$ m ~1m.
30. **E**—An element of current produces a magnetic field that wraps around the current element, pointing out of the page above the current and into the page below. But right in front (or anywhere along the axis of the current), the current element produces no magnetic field at all.
31. **D**—A long way from the hole, the magnet produces very little flux, and that flux doesn't change much, so very little current is induced. As the north end approaches the hole, the magnetic field points down. The flux is *increasing* because the field through the wire gets stronger with the approach of the magnet; so, point your right thumb upward (in the direction of *decreasing* flux) and curl your fingers. You find the current flows counterclockwise, defined as positive. Only A or D could be correct. Now consider what happens when the magnet leaves the loop. The south end descends away from the loop. The magnetic field still points down, into the south end of the magnet, but now the flux is *decreasing*. So point your right thumb down (in the direction of decreasing flux) and curl your fingers. Current now flows clockwise, as indicated in choice D. (While the magnet is going through the loop, current goes to zero because the magnetic field of the bar magnet is reasonably constant near the center of the magnet.)
32. **A**—You remember the equation for the induced EMF in a moving rectangular loop, $\varepsilon = Blv$. Here l represents the length of the wire that doesn't change within the field; dimension a in the diagram. So the answer is either A or C. To find the direction of induced current, use Lenz's law: The field points out of the page, but the flux through the loop is *increasing* as more of the loop enters the field. So, point your right thumb into the page (in the direction of decreasing flux) and curl your fingers; you find the current is clockwise, or left-to-right across the resistor.

33. **D**—Start by finding the direction of the induced current in the wire using Lenz's law: the magnetic field is out of the page. The flux *increases* because the field strength increases. So point your right thumb into the page, and curl your fingers to find the current flowing clockwise, or south in the wire. Now use the right-hand rule for the force on moving charges in a magnetic field (remembering that a current is the flow of positive charge). Point down the page, curl your fingers out of the page, and the force must be to the west.
34. **C**—There is clearly nonzero flux because the field does pass through the wire loop. The flux is not *BA*, though, because the field does not go *straight* through the loop—the field hits the loop at an angle. So is the answer *BA* cos 30°, using the angle of the plane; or *BA* cos 60°, using the angle from the vertical? To figure it out, consider the extreme case. If the incline were at zero degrees, there would be zero flux through the loop. Then the flux would be *BA* cos 90°, because cos 90° is zero, and cos 0° is one. So don't use the angle of the plane, use the angle from the vertical, *BA* cos 60°.
35. **C**—The inductor resists changes in current. But after a long time, the current reaches steady state, meaning the current does not change; thus the inductor, after a long time, might as well be just a straight wire. The battery will still provide current *I*, of which half goes through each equal resistor.

Free-Response Solutions

For answers that are numerical, or in equation form:

*For each part of the problem, look to see if you got the right answer. If you did, and you showed any reasonable (and correct) work, give yourself full credit for that part. It's okay if you didn't explicitly show EVERY step, as long as some steps are indicated and you got the right answer. However:

*If you got the WRONG answer, then look to see if you earned partial credit. Give yourself points for each step toward the answer as indicated in the rubrics below. Without the correct answer, you must show each intermediate step explicitly in order to earn the point for that step. (See why it's so important to show your work?)

*If you're off by a decimal place or two, not to worry—you get credit anyway, as long as your approach to the problem was legitimate. This isn't a math test. You're not being evaluated on your rounding and calculator-use skills.

*You do not have to simplify expressions in variables all the way. Square roots in the denominator are fine; fractions in non-simplified form are fine. As long as you've solved properly for the requested variable, and as long as your answer is algebraically equivalent to the rubric's, you earn credit.

*Wrong, but consistent: Often you need to use the answer to part (a) in order to solve part (b). But you might have the answer to part (a) wrong. If you follow the correct procedure for part (b), plugging in your incorrect answer, then you will usually receive *full credit* for part (b). The major exceptions are when your answer to part (a) is unreasonable (say, a car moving at 105 m/s, or a distance between two cars equal to 10–100 meters), or when your answer to part (a) makes the rest of the problem trivial or irrelevant.

For answers that require justification:

*Obviously your answer will not match the rubric word-for-word. If the general gist is there, you get credit.

*But the reader is not allowed to interpret for the student. If your response is vague or ambiguous, you will NOT get credit.

*If your response consists of both correct and incorrect parts, you will usually not receive credit. It is not possible to try two answers, hoping that one of them is right. (See why it's so important to be concise?)

CE&M 1

a.

1 pt: Inside a conductor, the electric field must always be zero. $E = 0$.

1 pt: Because we have spherical symmetry, use Gauss's law.

1 pt: The area of a Gaussian surface in this region is $4\pi r^2$. The charge enclosed by this surface is Q.

1 pt: So, $E = Q_{enclosed}/\varepsilon_o A = Q/4\pi\ \varepsilon_o r^2$.

1 pt: Inside a conductor, the electric field must always be zero. $E = 0$.

2 pts: Just as in part 2, use Gauss's law, but now the charged enclosed is $3Q$. $E = 3Q/4\pi\ \varepsilon_o r^2$.

b.

1 pt: $-Q$ is on the inner surface.

1 pt: $+3Q$ is on the outer surface.

1 pt: Because $E = 0$ inside the outer shell, a Gaussian surface inside this shell must enclose zero charge, so $-Q$ must be on the inside surface to cancel the $+Q$ on the small sphere. Then to keep the total charge of the shell equal to $+2Q$, $+3Q$ must go to the outer surface.

c.

1 pt: Because we have spherical symmetry, the potential due to both spheres is $3Q/4\pi\ \varepsilon_o r$, with potential equal to zero an infinite distance away.

1 pt: So at position R_3, the potential is $3Q/4\pi\ \varepsilon_o R_3$. (Since $E = 0$ inside the shell, V is the same value everywhere in the shell.)

d.

1 pt: Integrate the electric field between R_1 and R_2 to get $V = Q/4\pi\ \varepsilon_o r$ + *a* constant of integration.

1 pt: To find that constant, we know that $V(R_2)$ was found in part (c), and is $3Q/4\pi\varepsilon_o R_3$. Thus, the constant is

$$\frac{3Q}{4\pi\varepsilon_o R_3} - \frac{Q}{4\pi\varepsilon_o R_2}.$$

1 pt: Then, potential at $R_1 = Q/4\pi\varepsilon_o R_1$ + the constant of integration.

CE&M 2

a.

1 pt: The series capacitors add inversely,

$$\frac{1}{4\mu\text{F}} + \frac{1}{12\mu\text{F}} = \frac{1}{C_{eq}},$$

so C_{eq} for the series capacitors is 3 µF.

1 pt: The parallel capacitor just adds in algebraically, so the equivalent capacitance for the whole system is 5 µF.

b.

1 pt: After a long time, the resistor is irrelevant; no current flows because the fully charged capacitors block direct current.

1 pt: The voltage across C3 is 10 V (because there's no voltage drop across the resistor without any current).

1 pt: By $Q = CV$ the charge on C_3 is 20 µC.

1 pt: Treating C_1 and C_2 in series; the equivalent capacitance is 3 µF, the voltage is 10 V (in parallel with C_3).

1 pt: The charge on the equivalent capacitance of C_1 and C_2 is 30 µC; thus the charge on C_1 = 30 µC, and the charge on C_2 is also 30 µC (charge on series capacitors is the same).

1 pt: Using $Q = CV$, the voltage across C_1 is 7.5 V.

1 pt: Using $Q = CV$, the voltage across C_2 is 2.5 V.

c.

1 pt: For a graph that starts at $Q = 0$.

1 pt: For a graph that asymptotically approaches 20 µC (or whatever charge was calculated for C_3

in part b).

1 pt: For calculating the time constant of the circuit, RC = 5 s.

1 pt: For the graph reaching about 63% of its maximum charge after one time constant.

d.

1 pt: For recognizing that the voltage does not change.

1 pt: For explaining that if voltage changed, then Kirchoff 's voltage rule would not be valid around a loop including C_3 and the battery (or explaining that voltage is the same across parallel components, so if one is disconnected the other's voltage is unaffected)

CE&M 3

a.

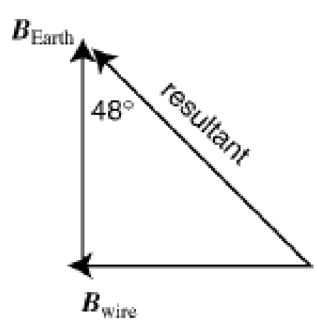
1 pt: For placing the wire along a north–south line.

1 pt: The wire could be placed above the compass, with the current traveling due north. (The wire also could be placed underneath the compass, with current traveling due south.) (Points can also be earned for an alternative correct solution: for example, the wire could be placed perpendicular to the face of the compass (just south of it), with the current running up.)

b.

1 pt: The *B* field due to Earth plus the *B* field caused by the wire, when added together as vectors, must give a resultant direction of 48° west of north.

1 pt: Placing these vectors tail-to-tip, as shown below, tan 48° = B_{wire}/B_{Earth}.



1 pt: So $B_{wire} = B_{Earth}\tan 48° = 5.6 \times 10^{-5}$ T.

c.

1 pt: The magnetic field due to a long, straight, current-carrying wire is given by

$$B = \frac{\mu_o I}{2\pi r},$$

where *r* is the distance from the wire to the field point, represented in this problem by *d*.

1 pt: So *B* is proportional to 1/*d*; this results in a hyperbolic graph.

1 pt: This graph should be asymptotic to both the vertical and horizontal axes.

d.

1 pt: Place 1/*d* on the horizontal axis.

2 pts: The equation for the field due the wire can be written

$$B = \left(\frac{\mu_o I}{2\pi}\right)\left(\frac{1}{d}\right).$$

Everything in the first set of parentheses is constant. So, this equation is of the form $y = mx$, which is the equation of a line, if 1/*d* is put on the *x*-axis of the graph. (1 point can be earned for a partially complete explanation. On this problem, no points can be earned for justification if the answer is incorrect.)

e.

1 pt: The slope of the graph, from the equation above, is

$$\frac{\mu_o I}{2\pi}.$$

1 pt: For plugging in values correctly, including 0.5 A or 500 mA.

1 pt: For units on the slope equivalent to magnetic field times distance (i.e., T·m, T·cm, mT·m, etc.).

1 pt: For a correct answer, complete with correct units: 1.0×10^{-7} Tm, or 1.0×10^{-4} mT·m.

AP Physics C—Electricity and Magnetism

Full Exam Scoring

Multiple-Choice: Number Correct______
Number Wrong______

Total = Right – ($^1/_4$) Wrong______35 max

Free-Response: Question 1______15 max
Question 2______15 max
Question 3______15 max

Total Free-Response______45 max

1.286 × Multiple-Choice + Free-Response = Raw Score______90 max

52–90	5
39–51	4
26–38	3
15–25	2
0–14	1

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