CollegeBoard

AP® Physics C: Electricity and Magnetism Practice Exam

From the 2015 Administration

PHYSICS C: ELECTRICITY AND MAGNETISM

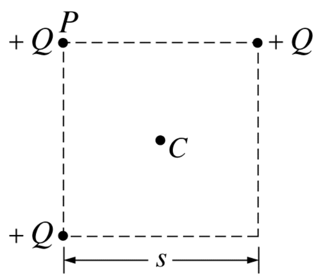
SECTION I

Time—45 minutes

35 Questions

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

Questions 1-2



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

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

(A) $\longrightarrow$

(B) $\longleftarrow$

(C) $\nwarrow$

(D) $\swarrow$

(E) $\searrow$

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

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

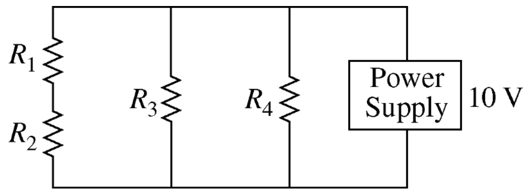
(B) $\dfrac{2kQ}{s}$

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

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

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

Questions 3-4



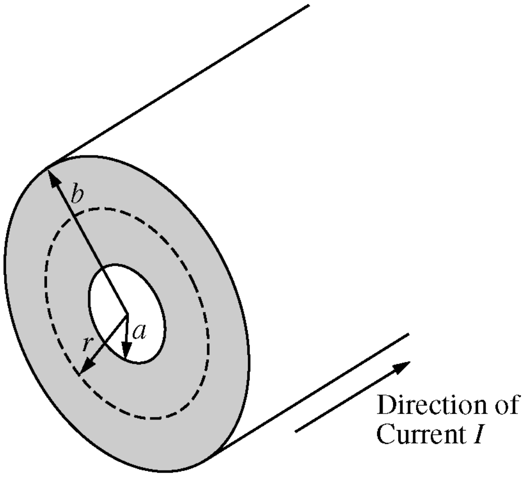
Four resistors, all with the same resistance R, are connected as shown above.

3. What is the equivalent resistance of the network?

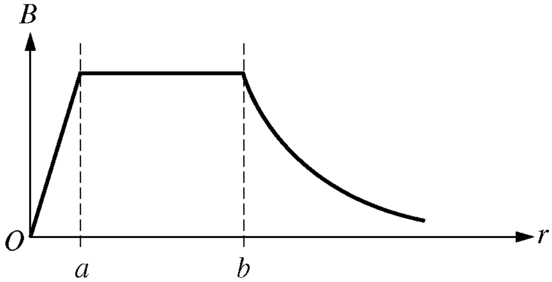
(A) $4R$
(B) $3R$
(C) $5R/2$
(D) R
(E) $2R/5$

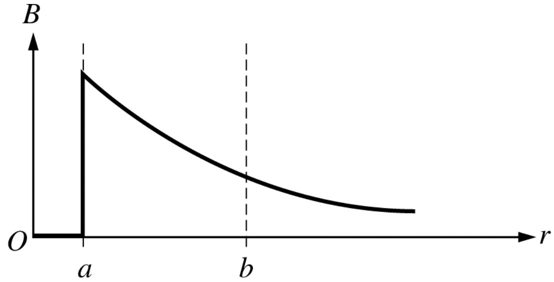
4. If the power supply produces 10 V and the resistance R is $5\ \Omega$, what is the current in resistor R_4?

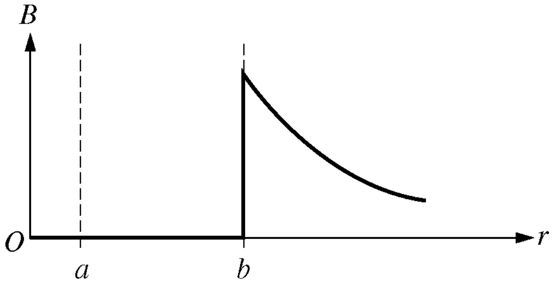
(A) 15 A
(B) 5 A
(C) 2 A
(D) $1/2$ A
(E) $1/5$ A

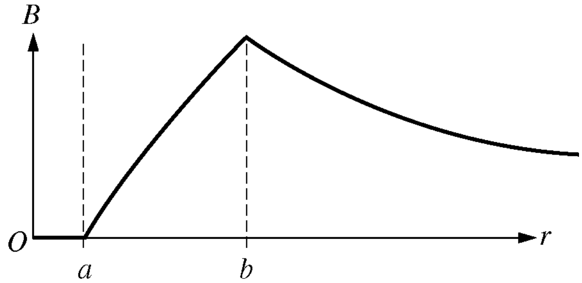


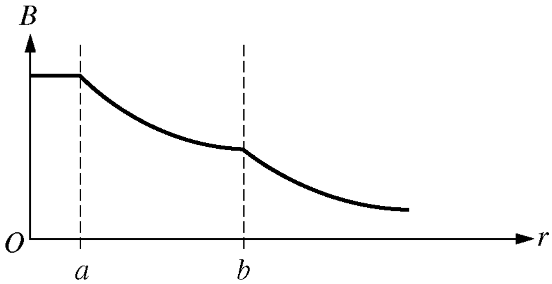
5. A long, cylindrical conductor with inner radius a and outer radius b carries a current I distributed uniformly over its cross section (the shaded region shown above). Which of the following graphs best shows the magnitude of the magnetic field B as a function of the distance r from the axis of the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

(A) 

(B) 

(C) 

(D) 

(E) 

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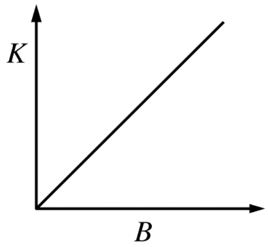
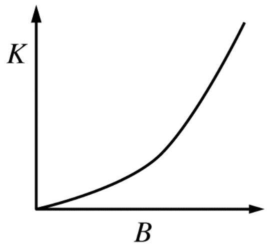
6. A positron (charge $+e$, mass m_e) moves in a circular path of radius R due to a uniform magnetic field of strength B applied perpendicular to the plane of the circle. If B is varied, which of the following best represents a graph of the kinetic energy of the positron as a function of B so that the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

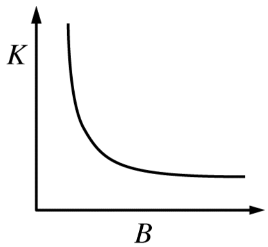
(A)



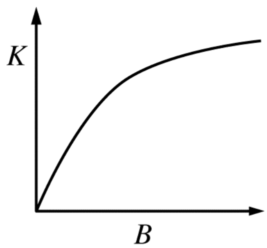
(B)



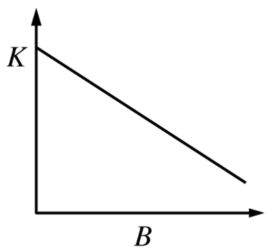
(C)



(D)



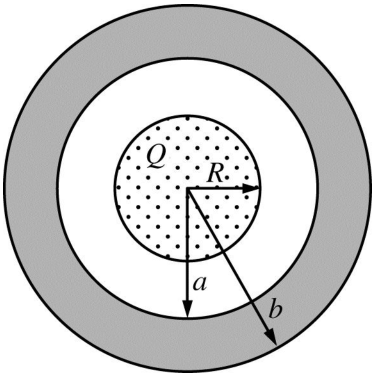
(E)



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

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

Questions 8-9



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

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

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

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

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

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

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

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

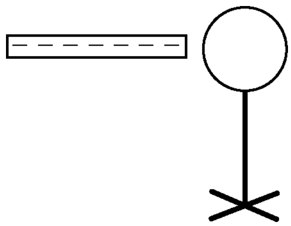
(A) $0 = E(4\pi)r^2$

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

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

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

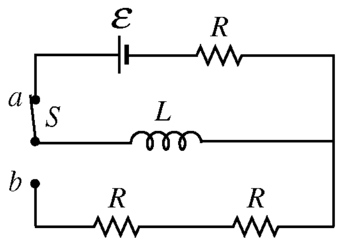
(E) $\dfrac{Qa^3}{\epsilon_0 R^3} = E(4\pi)r^2$



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

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

Questions 11-13



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

11. What is the energy stored by the inductor?

(A) Zero

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

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

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

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

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

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

13. The time constant when the switch is in position a is τ_0. How does the time constant when the switch is in position b compare to τ_0?

(A) It is zero.
(B) It is less than τ_0 but greater than zero.
(C) It is equal to τ_0.
(D) It is greater than τ_0 but not infinite.
(E) It is infinite.

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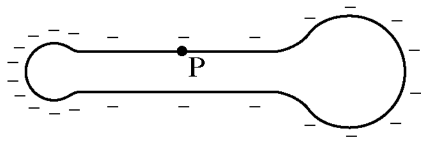
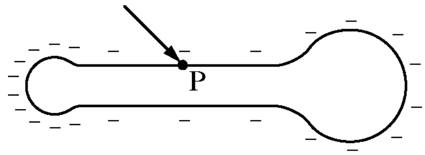
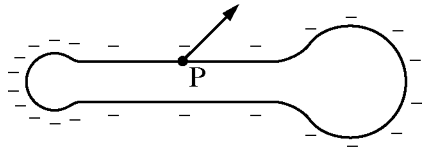
14. If a dielectric is inserted between the plates of a capacitor while the capacitor maintains its connection to a constant voltage source, which of the following is true?

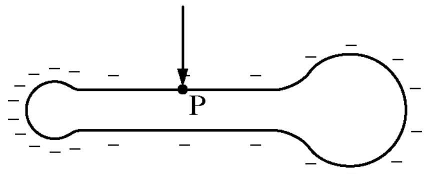
    (A) The capacitance of the capacitor is unchanged.
    (B) The charge on the capacitor plates increases.
    (C) The potential difference across the capacitor increases.
    (D) The electric field between the capacitor plates increases.
    (E) The electric field between the capacitor plates decreases.

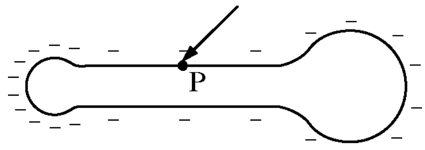


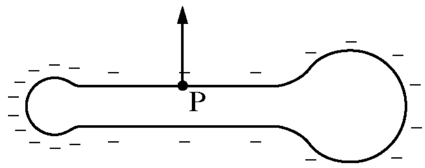
15. The conductor shown above is given a negative charge that spreads over its surface. Which of the following best represents the direction of the electric field at the point P on the cylindrical portion of the conductor?

    (A)


    (B)


    (C)


    (D)


    (E)


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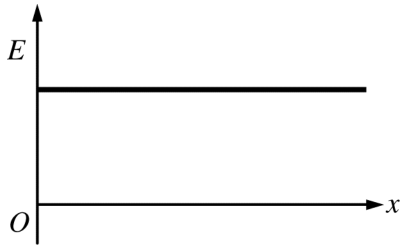
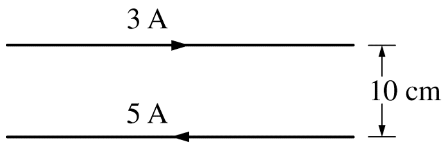


16. The graph above shows the electric field E as a function of x, where x is the distance from a given charge arrangement in an xyz-coordinate system. Which of the following could be the arrangement?

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

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

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



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

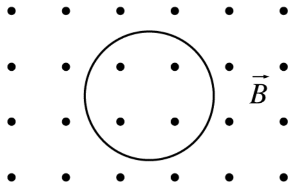
(A) $\dfrac{20 \times 4\pi \times 10^{-7}}{\pi}$

(B) $\dfrac{40 \times 4\pi \times 10^{-7}}{\pi}$

(C) $\dfrac{80 \times 4\pi \times 10^{-7}}{\pi}$

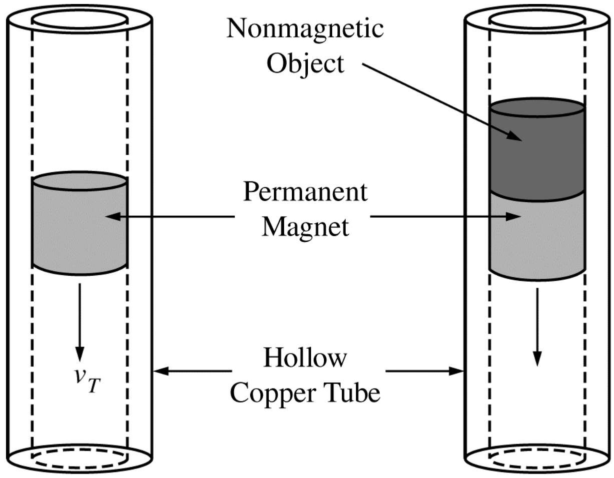
(D) $\dfrac{100 \times 4\pi \times 10^{-7}}{\pi}$

(E) $\dfrac{160 \times 4\pi \times 10^{-7}}{\pi}$



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

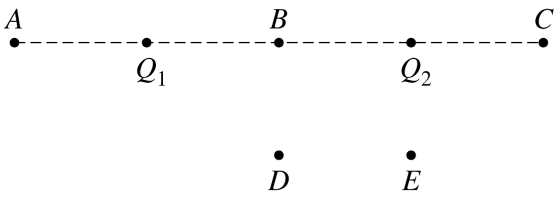
(A) 0.4 V
(B) 1.6 V
(C) 2.0 V
(D) 4.0 V
(E) 8.0 V



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

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

Questions 21-22



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

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

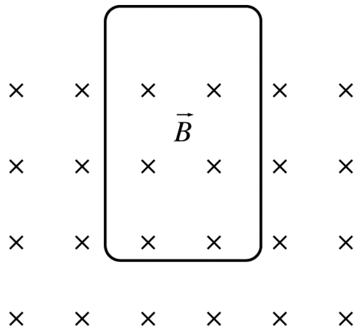
(A) *A*
(B) *B*
(C) *C*
(D) *D*
(E) *E*

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

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

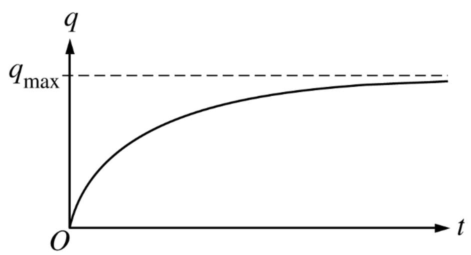
23. A loop of wire with resistance $2\ \Omega$ lies in a magnetic field. The magnetic flux ϕ_m through the loop as a function of time *t* is given by $\phi_m = (2t^2 + 2t)$, where ϕ_m is in tesla • meters squared and *t* is in seconds. What is the current in the loop at $t = 3$ s ?

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



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

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

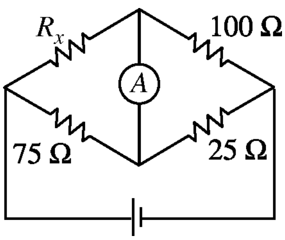


25. A capacitor of capacitance C is connected in series with resistance R and a battery of emf $\mathcal{E}$. The graph above shows the charge q on the capacitor approaching a value q_{max} with increasing time t. What is q_{max} ?

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

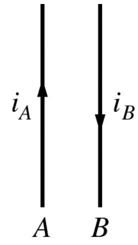
26. A 9 V battery is connected to a 450 Ω load. If the internal resistance of the battery is negligible, how long will it take for 2 C to pass through the load?

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



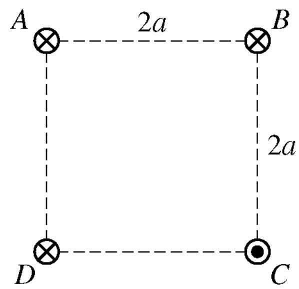
27. In the circuit shown above, the resistances have the values given and there is no current in the ammeter A. What is the value of R_x ?

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



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

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



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

(A) $\dfrac{\mu_0 I}{\sqrt{2}\pi a}$ toward wire D

(B) $\dfrac{\mu_0 I}{\sqrt{2}\pi a}$ toward wire B

(C) $\dfrac{\mu_0 I}{\sqrt{2}\pi a}$ toward the bottom of the page

(D) $\dfrac{\mu_0 I}{2\pi a}$ toward wire D

(E) $\dfrac{\mu_0 I}{2\pi a}$ toward wire B

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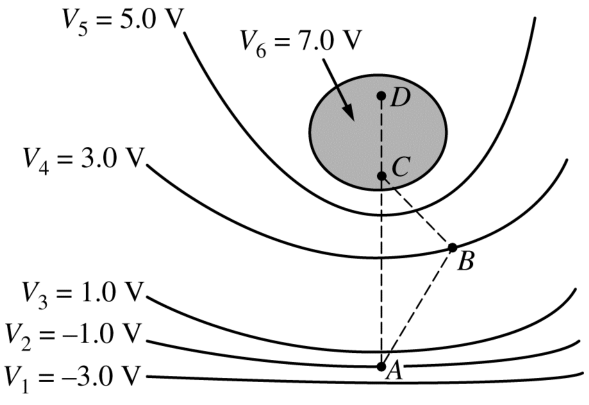
Questions 30-31



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

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

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

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

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

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

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

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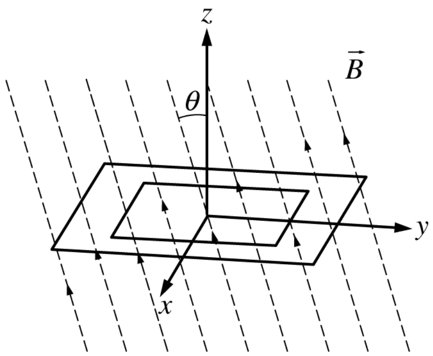

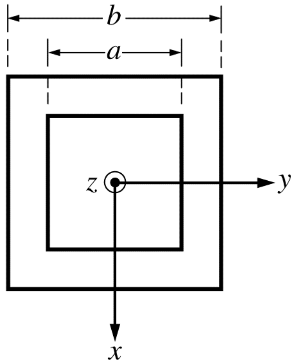

Top View

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

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

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

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

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

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

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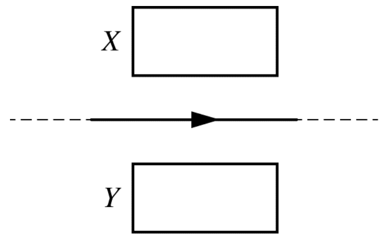
Questions 34-35



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

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

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

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

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

S T O P

END OF ELECTRICITY AND MAGNETISM SECTION I

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

DO NOT TURN TO ANY OTHER TEST MATERIALS.

MAKE SURE YOU HAVE DONE THE FOLLOWING.

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

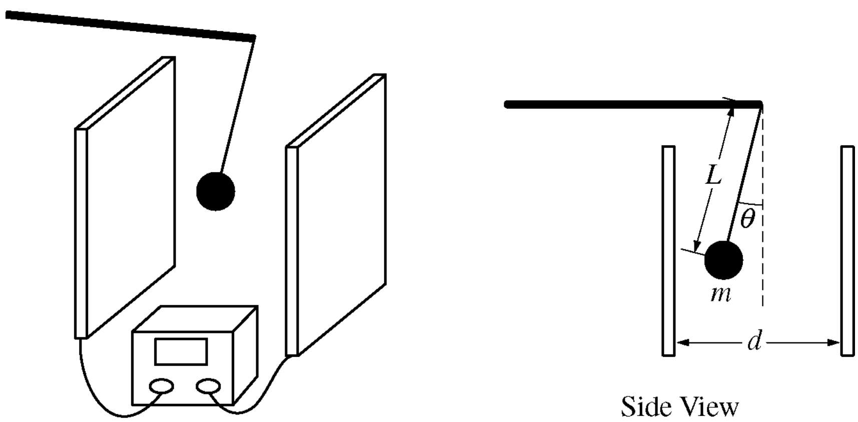
PHYSICS C: ELECTRICITY AND MAGNETISM

SECTION II

Time—45 minutes

3 Questions

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

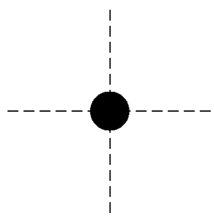


Side View

E&M. 1.

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

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



GO ON TO THE NEXT PAGE.

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

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

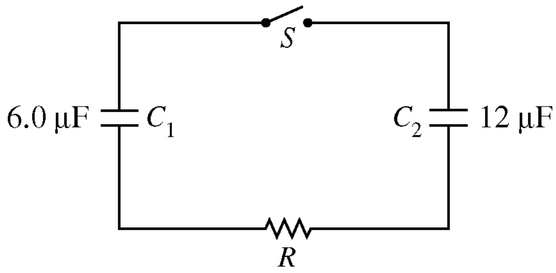
i. What quantity would you vary in this experiment to obtain different values of the angle θ?

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

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

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

GO ON TO THE NEXT PAGE.



E&M. 2.

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

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

The switch is now closed.

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

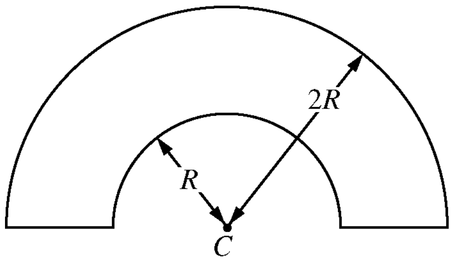
(c) Calculate the final charges Q_1 and Q_2 on the two capacitors after equilibrium is reached.

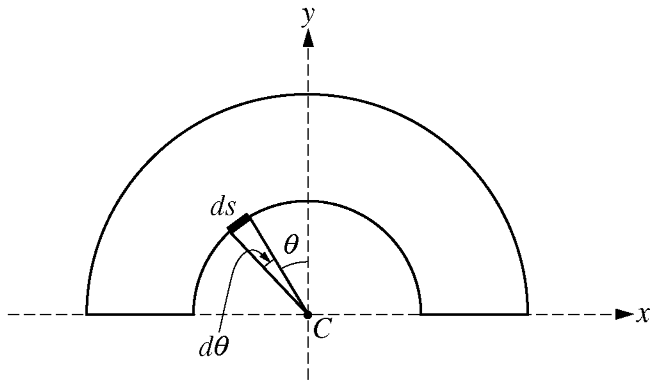
(d) Calculate the energy dissipated in the circuit as the charge is redistributed.

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

____ Longer ____ The same ____ Shorter

Justify your answer.





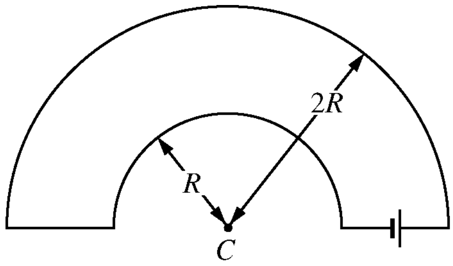
E&M. 3.

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

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

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

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



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

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

THIS PAGE MAY BE USED FOR SCRATCH WORK.

STOP

END OF EXAM

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

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