CollegeBoard
Advanced Placement Program

AP® Physics C: Electricity and Magnetism

Practice Exam

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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,	$G = 6.67 \times 10^{-11}$ m^3/kg•s^2
Universal gas constant,	$R = 8.31$ J/(mol•K)	Acceleration due to gravity at Earth's surface,	$g = 9.8$ m/s^2
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K		

1 unified atomic mass unit,	$1 \text{ u} = 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J•s $= 4.14 \times 10^{-15}$ eV•s
	$hc = 1.99 \times 10^{-25}$ J•m $= 1.24 \times 10^{3}$ eV•nm
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}$ C^2/N•m^2
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}$ N•m^2/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,	$1 \text{ atm} = 1.0 \times 10^{5}$ 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.

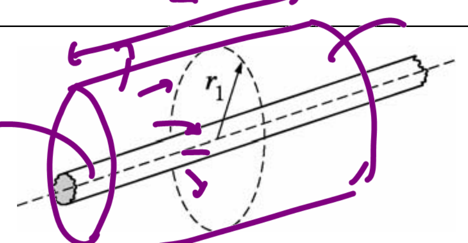
1. Two negative point charges are a distance x apart and have potential energy U. If the distance between the point charges increases to $3x$, what is their new potential energy?

D

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

$U_q = \frac{kq_1q_2}{r}$ $x \to 3x$

$Q = \gamma L$



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 $\frac{E_1}{4}$?

D

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

$\oint E\cdot dA = \frac{Q}{\varepsilon_0}$

$E\cdot A = \frac{Q}{\varepsilon_0}$

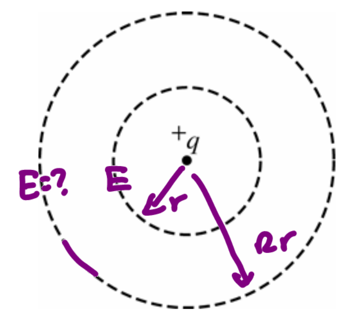
$E\cdot 2\pi r\cancel{L} = \frac{\gamma\cancel{L}}{\varepsilon_0}$

$E = \frac{\gamma}{2\pi\varepsilon_0 r}$

$E \propto \frac{1}{r_1} \to 4r_1$

$E \to \frac{1}{4}E$

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

$\Phi_q = \oint E\cdot dA = \frac{q}{\varepsilon_0}$

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) $4E$

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

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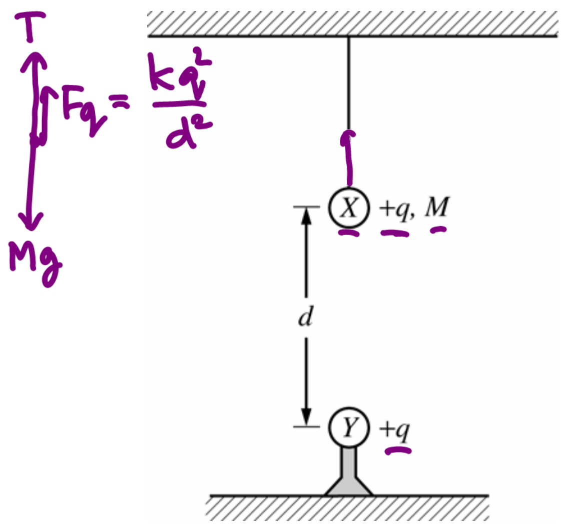
$T + \frac{kq^2}{d^2} = Mg$

$T = Mg - \frac{kq^2}{d^2}$



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

$\Sigma \vec{F} = 0 \rightarrow$ equilibrium, the tension in the string is most nearly

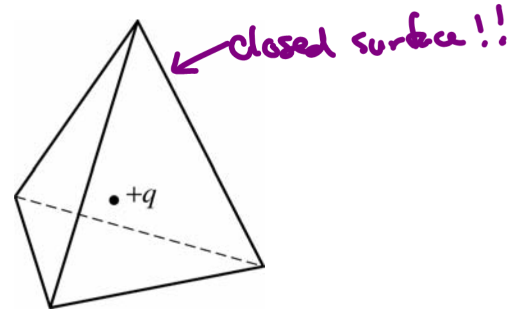
(A) Mg

(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?

$\Phi = \oint E \cdot dA = \frac{q}{\varepsilon_0}$

(A) 0

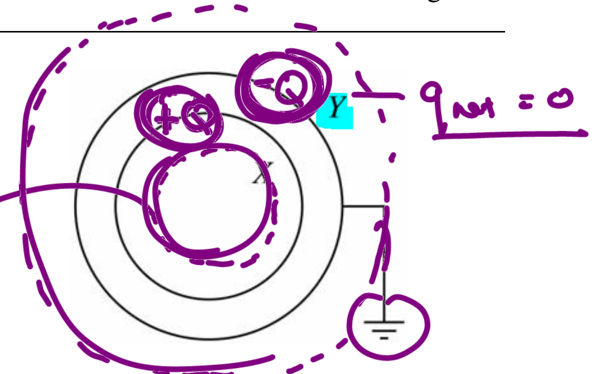
(B) $\frac{q}{\epsilon_0}$

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

each face $\frac{\Phi}{4} = \frac{q}{4\varepsilon_0}$

(D) $4\epsilon_0 q$

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



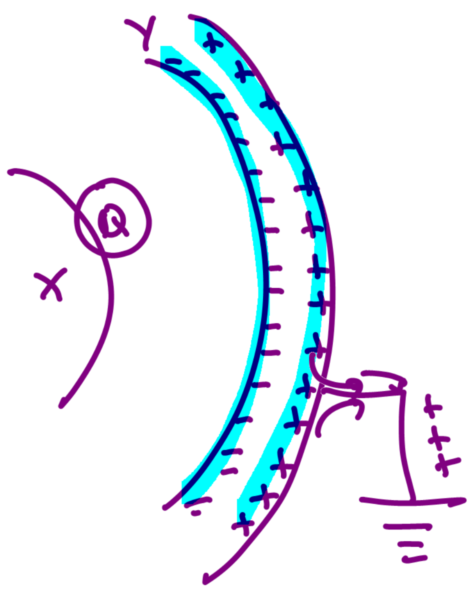
no charges inside

$\therefore E = 0$

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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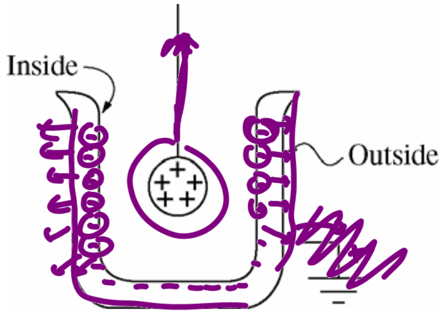
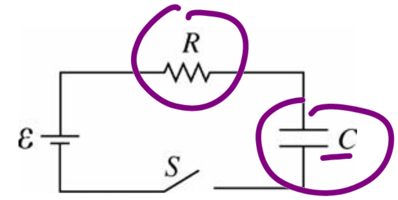


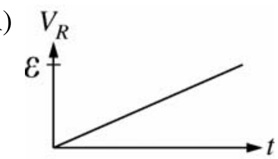
8. A small positively charged sphere is lowered by a nonconducting thread into a grounded metal cup without touching the inside surface of the cup, as shown above. The grounding wire attached to the outside surface is disconnected and the charged sphere is then removed from the cup. Which of the following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

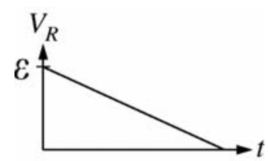
(A) Negative charge resides on the inside surface, and no charge resides on the outside surface.
(B) Negative charge resides on the outside surface, and no charge resides on the inside surface.
(C) Positive charge resides on the inside surface, and no charge resides on the outside surface.
(D) Positive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

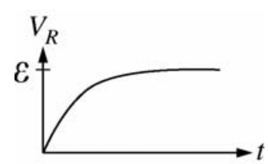
$V_R = IR \leftarrow I = I_0 e^{-t/\tau}$

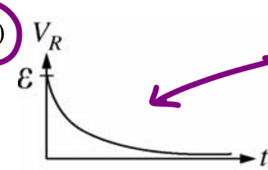


9. The capacitor C in the circuit shown above is initially uncharged. The switch S is then closed. Which of the following best represents the voltage V_R across the resistor R as a function of time t?

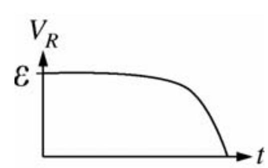
(A)


(B)


(C)


(D)


decays exponentially.

(E)


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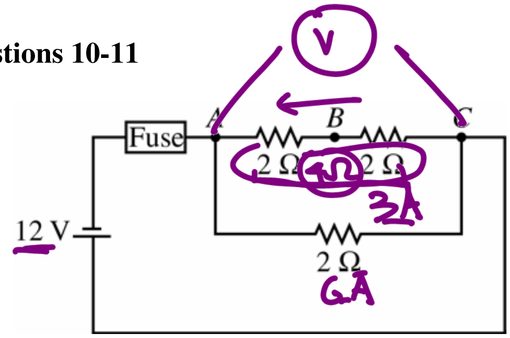
Questions 10-11



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

(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 ?

C

$I=\frac{V}{R}$

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

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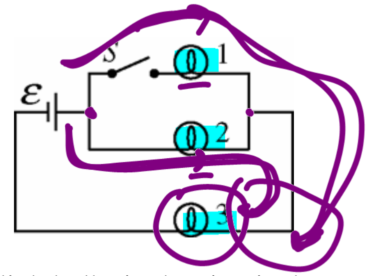
12. A fixed voltage is applied across the length of a tungsten wire. An increase in the power dissipated by the wire would result if which of the following could be increased?

B

(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 ??

$$\uparrow P = IV = \frac{V^2}{R} = \frac{V^2 A\uparrow}{\downarrow\rho L\downarrow}$$

$\frac{V}{R}$ $\rho\frac{L}{A}$



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?

C

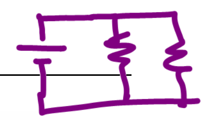
(A) Neither bulb
(B) Bulb 2 only
(C) Bulb 3 only
(D) Both bulbs
(E) It cannot be determined without knowing the emf of the battery.

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?

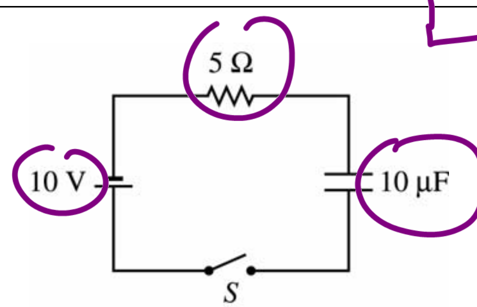
$R=\rho\frac{L}{A}$

E

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



$R = \frac{1}{4}R$



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

$U=\frac{1}{2}CV^2$

$U = \frac{1}{2}(10\times10^{-6})(100)$

10^{-3}

500×10^{-6}

5×10^{-4}

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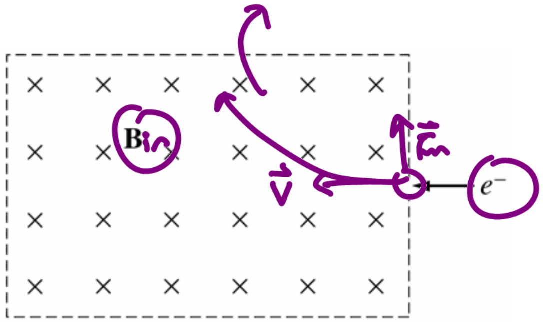

16. An electron e^- moving in the plane of the page is injected into a uniform magnetic field **B** that is perpendicular to the page, as shown above. Upon entering the field, the electron takes a path that is

B

(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

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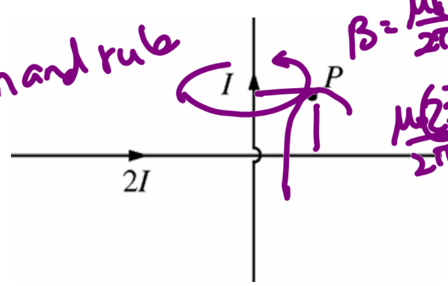
right hand rule

$B = \frac{\mu_0 I}{2\pi}$



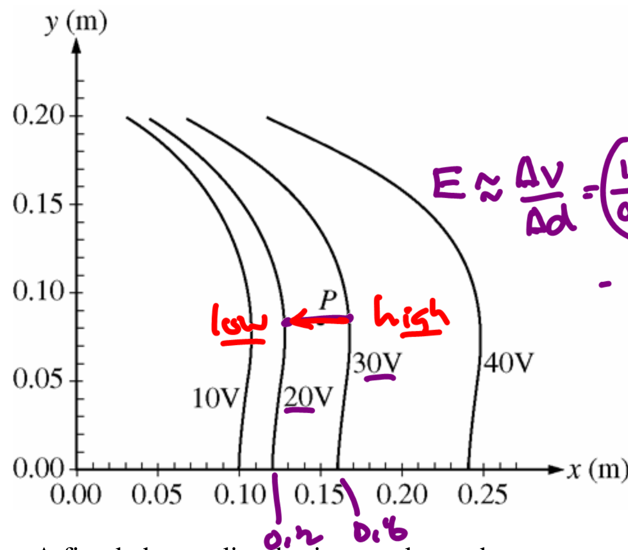
$\frac{\mu_0 2I}{2\pi}$

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?

B

(A) Into the page
(B) Out of the page
(C) $\searrow$
(D) $\nwarrow$
(E) $\nearrow$

Questions 18-19



$E \approx \frac{\Delta V}{\Delta d} = \frac{10}{0.04}$

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) $\frac{10\text{ V}}{0.14\text{ m}}$

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

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

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

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

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

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E

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, $\frac{K_{lithium}}{K_{helium}}$? $\frac{3q}{2q}$

V_0

$\Delta K = q\Delta V$

ΔU_q

$K = qV_0$

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

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

(C) 1

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

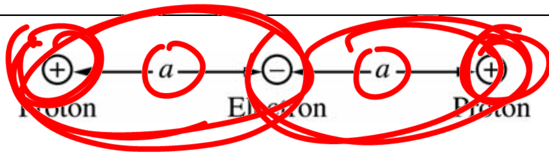
(E) $\frac{3}{2}$

C

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 $(-1, 2)$?

$E = -\frac{\partial V}{\partial x}\hat{i} - \frac{\partial V}{\partial y}\hat{j}$

(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?

B

P-e $\frac{-ke^2}{a}$

$\frac{-ke^2}{a}$

P-p $= +\frac{ke^2}{2a}$

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

$U_q = \frac{ke^2}{2a} - \frac{4e^2}{2a}$

$= \frac{-3ke^2}{2a}$

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?

$\frac{Q}{R}$

	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

$\frac{Q}{R}$ $\frac{4}{3}\pi R^3$ $\frac{Q}{R}$ $\frac{4}{3}\pi R^3$

$\frac{2Q}{R'}$

$\frac{8}{3}\pi R^3$

$\frac{4}{3}\pi$

$R \to$

(A) $3V_0$

(B) $2V_0$

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

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

(E) V_0

$\frac{\partial V}{\partial y} = 6x^2 - 6y^2 \Big|_{(-1,2)}$

$= 6(1) - 6(4) = -18$

$V(x, y) = 6x^2y - 2y^3$

$E = -\nabla V$

$-\underbrace{\left(\frac{\partial V}{\partial x}\hat{i} + \frac{\partial V}{\partial y}\hat{j}\right)}_{\nabla V}$

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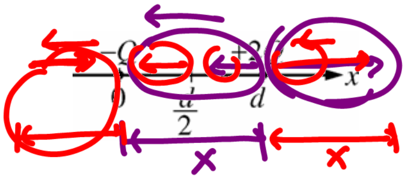


25. A point charge $-Q$ is located at the origin, while a second point charge $+2Q$ is located at $x = d$ on the x-axis, as shown above. A point on the x-axis where the net electric field is zero is located in which of the following regions?

A

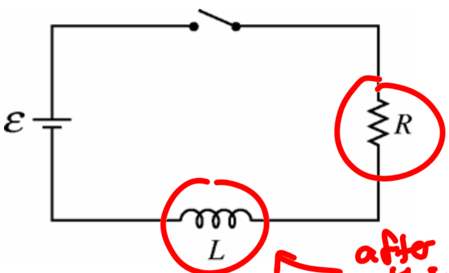
(A) $-\infty < x < 0$

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

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

(D) $d < x < \infty$

(E) No region on the x-axis



after long time this acts like a short.

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}?

$I = \frac{\mathcal{E}}{R}$

D

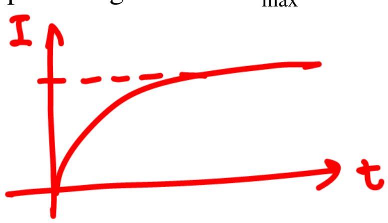
(A) $R/L\mathcal{E}$

(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 4.0×10^{-3} m^2, what is the time interval during which the field is increased?

A

(A) 2.0 μs

(B) 5.0 μs

(C) 10 μs

(D) 20 μs

(E) 50 μs

$20 = \mathcal{E} = \frac{d\phi}{dt} \quad \frac{(1.0\times10^{-2})(4\times10^{-3})}{\Delta t}$

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?

$\Delta t = \frac{4.0\times10^{-5}}{20}$

2.0×10^{-6}

(A) 0.040 W

(B) 0.80 W

(C) 1.25 W

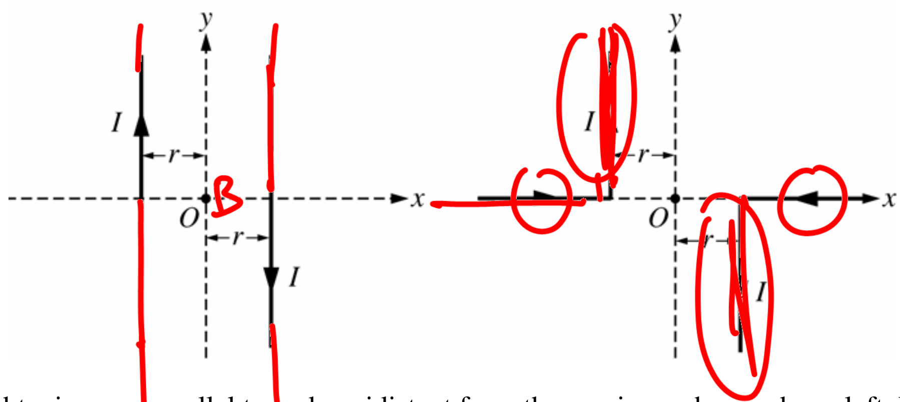
(D) 25 W

(E) 1.0×10^4 W

$P = \frac{V^2}{R} = \frac{20^2}{500} = \frac{400}{500}$

$= 0.8$ W

GO ON TO THE NEXT PAGE.



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?

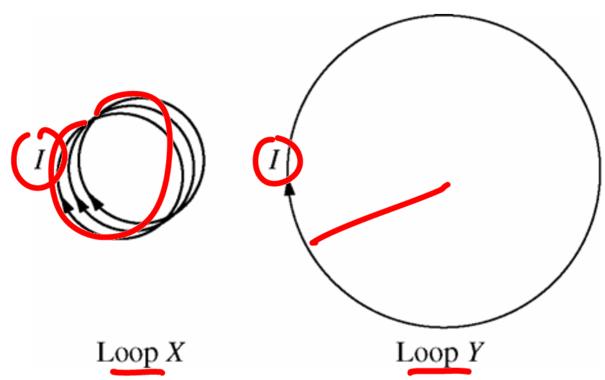
(A) Zero

(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

GO ON TO THE NEXT PAGE.

$\int \vec{B}\cdot d\vec{l} = \mu_0 I$

$B\cdot l$

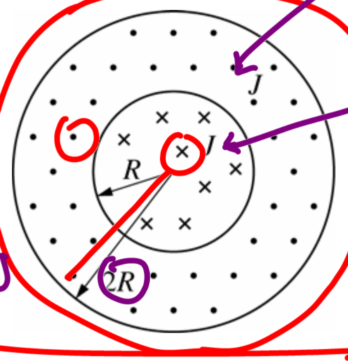
$B\cdot 2\pi(2R)$

$B(\cancel{4\pi R}) = 2\pi R^2 J$ μ_0 2

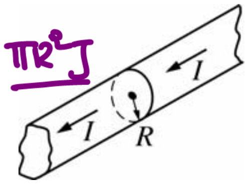
$I_{out} = JA = J(\pi(2R)^2 - \pi R^2) = 3\pi R^2 J$

$I_{in} = JA = J(\pi R^2) = \pi R^2 J$

$I_0 = 2\pi R^2 J$



$B = \frac{1}{2}\mu_0 R J$



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?

$= 2\pi J R^2$

(A) Zero

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

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

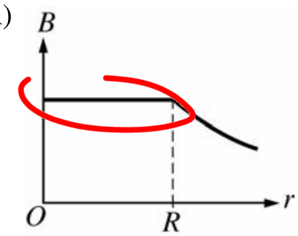
(D) $\frac{3}{4}\mu_0 RJ$

(E) $\mu_0 RJ$

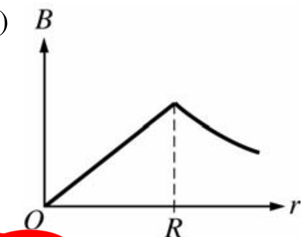
C

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 ?

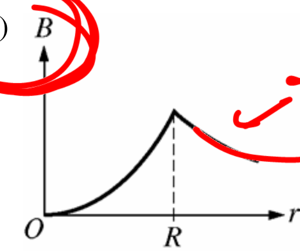
(A)



(B)

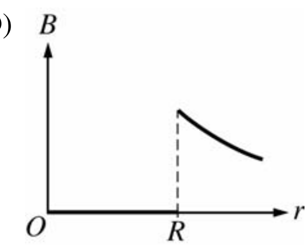


(C)

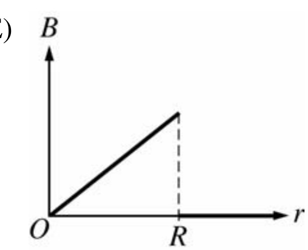


$\propto \frac{1}{r}$

(D)



(E)



$\int \alpha r \cdot dr$

$\frac{1}{2}\alpha r^2$

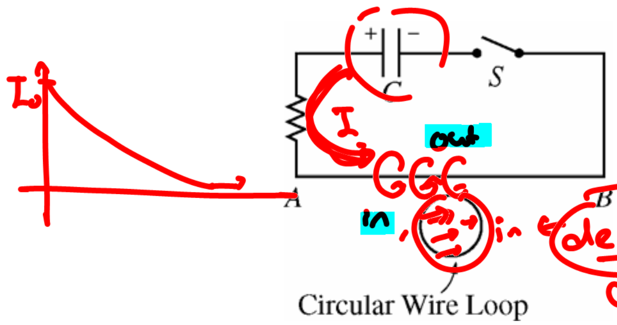
$I = \int_0^r J\,dr = \frac{1}{2}\alpha r^2$

$B \propto I \propto r^2$

$-\int B\cdot dl = \mu_0 I$

$2\pi r$

$\oint B \cdot dA = 0$



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. ✓ Ampere's law.
(B) A changing electric field produces a magnetic field. ✓ Faraday's law
(C) The net magnetic flux through a closed surface depends on the current inside. $\oint B \cdot dA = 0$
(D) The net electric flux through a closed surface depends on the charge inside. ✓ Gauss's law
(E) The electric field due to an isolated stationary point charge is inversely proportional to the square of the distance from the charge. ✓ $\oint E \cdot dA = \frac{q}{\varepsilon_0}$

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

$\uparrow \omega = \frac{1}{\sqrt{CL}} \downarrow$

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

STOP

END OF ELECTRICITY AND MAGNETISM SECTION I

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

DO NOT TURN TO ANY OTHER TEST MATERIALS.

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 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,	$G = 6.67 \times 10^{-11}$ m^3/kg•s^2
Universal gas constant,	$R = 8.31$ J/(mol•K)	Acceleration due to gravity at Earth's surface,	$g = 9.8$ m/s^2
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K		

1 unified atomic mass unit,	1 u $= 1.66 \times 10^{-27}$ kg $= 931$ MeV$/c^2$
Planck's constant,	$h = 6.63 \times 10^{-34}$ J•s $= 4.14 \times 10^{-15}$ eV•s
	$hc = 1.99 \times 10^{-25}$ J•m $= 1.24 \times 10^3$ eV•nm
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}$ C^2/N•m^2
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9$ N•m^2/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 atm $= 1.0 \times 10^5$ N/m^2 $= 1.0 \times 10^5$ Pa

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

PREFIXES

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

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

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

The following 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

$$v = v_0 + at$$

$$x = x_0 + v_0 t + \frac{1}{2}at^2$$

$$v^2 = v_0^2 + 2a(x - x_0)$$

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

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

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

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

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

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

$$K = \frac{1}{2}mv^2$$

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

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

$$\Delta U_g = mgh$$

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

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

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

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

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

$$v = r\omega$$

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

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

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

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

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
v = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque
ω = angular speed
α = angular acceleration

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

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

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

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

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

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

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

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
v = 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

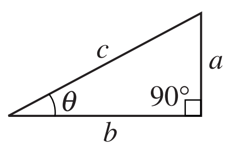
$a^2 + b^2 = c^2$

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

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

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

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



CALCULUS

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

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

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

$$\frac{d}{dx}(1\text{n}\,x) = \frac{1}{x}$$

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

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

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

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

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

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

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

PHYSICS C: ELECTRICITY AND MAGNETISM

SECTION II

Time—45 minutes

3 Questions

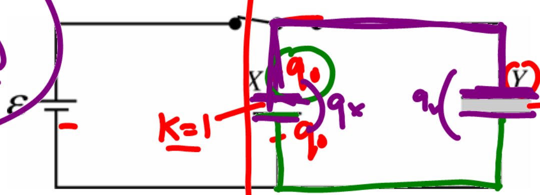
Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. All final numerical answers should include appropriate units. Credit depends on the quality of your 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.

$Q = CV$ $\rightarrow$ $q_0 = C\mathcal{E}$, $C = \frac{\varepsilon_0 A}{d}$

$C_x = \frac{\varepsilon_0 A}{d}$

$C_y = \frac{(3\varepsilon_0)(2A)}{d}$

$C_y = 6C_x$



$K=1$ $K=3$

$\boxed{q_x + q_y = q_0}$

$\boxed{V_x = V_y}$ $\boxed{Q = CV}$

$\frac{q_x}{C_x} = \frac{q_y}{C_y}$

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.

$\boxed{q_0 = \frac{\varepsilon_0 A}{d}\mathcal{E}}$

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.

$\frac{q_x}{\cancel{C_x}} = \frac{q_y}{6C_x} = \frac{q_0 - q_x}{6\cancel{C_x}} \rightarrow q_x = \frac{q_0 - q_x}{6} \rightarrow 6q_x = q_0 - q_x$

$\boxed{q_x = \frac{q_0}{7}}$ $\boxed{q_y = \frac{6q_0}{7}}$

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

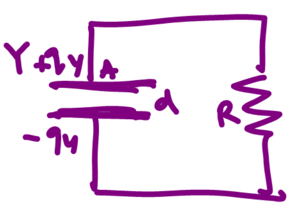
Justify your answer. dielectric : store more charge but do less work

(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. you have to pull it out with an external force (+) positive work.

(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.



voltage $\frac{q_y}{C_y} = IR \rightarrow \frac{q_y}{C_y} = \frac{dq_y}{dt} R \rightarrow q(t) = q_y e^{-t/RC}$

$C_y = \frac{6\varepsilon_0 A}{d}$

$\boxed{q(t) = q_y e^{-\frac{td}{6\varepsilon_0 A}}}$

GO ON TO THE NEXT PAGE.

Conservation of energy

$K = eV_0 \leftarrow \Delta U$

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

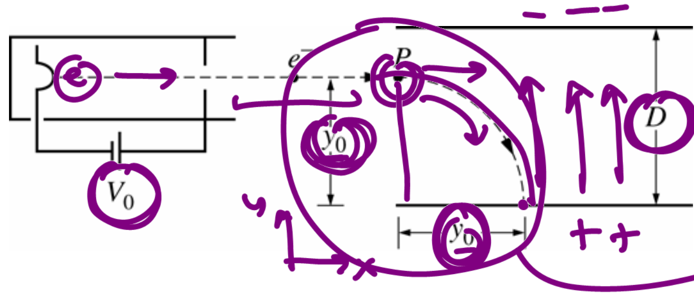
$\boxed{v = \sqrt{\frac{2eV_0}{m_e}}}$

electrostatics

$F_e = eE$

$a = \frac{eE}{m_e}$

projectile motion problem



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. $E = ??$

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. electrons are attracted to the bottom plate ∴ ie electric points from bottom to top.

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

$V = E\cdot d$

$= \left(\frac{4V_0}{y_0}\right)(D)$

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

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.

circular motion

(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.

$y_0 = \frac{1}{2}at^2$

$y_0 = \frac{1}{2}\left(\frac{eE}{m_e}\right)t^2$

$t = \sqrt{\frac{2y_0 m_e}{eE}}$

$y_0 = vt$

$y_0 = \sqrt{\frac{2\cancel{e}V_0}{\cancel{m_e}}}\sqrt{\frac{2y_0 \cancel{m_e}}{\cancel{e}E}}$

$y_0^2 = (2V_0)\left(\frac{2y_0}{E}\right)$

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

projectile motion

(a) $qvB = \frac{mv^2}{R}$

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

$\boxed{B = \sqrt{\frac{2m_eV_0}{e y_0^2}}}$

GO ON TO THE NEXT PAGE.

a) $\Phi_m = B_z \cdot A$

$\Phi_m = \boxed{B_0(1-kz)(\pi r_0^2)}$ ← $\frac{d\Phi}{dt} =$

(c) $\mathcal{E} = -\frac{d\Phi}{dt} = (B_0 \pi r_0^2)k\frac{dz}{dt}$, v

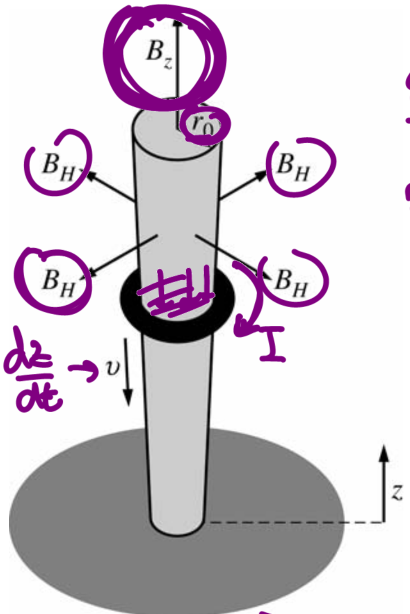
$\mathcal{E} = B_0 \pi r_0^2 k v$

$P = \frac{V^2}{R} = \frac{\mathcal{E}^2}{R} = \boxed{\frac{B_0^2 \pi^2 r_0^4 k^2 v^2}{R}}$

b) as the ring falls, z decreases
∴ B_z increases
∴ Φ_m increases
∴ induced current will decrease Φ_m

$\boxed{\text{∴ I runs clockwise}}$

(generates a downward $\vec{B}$ that opposes B_z)



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 (F_m) 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.

$F_m = \underbrace{I}_{\frac{\mathcal{E}}{R}} \underbrace{l}_{2\pi r_0} \underbrace{B}_{B_H} = \frac{B_0 \pi r_0^2 k v}{R}(2\pi r_0)B_H = \boxed{\frac{2\pi^2 r_0^3 B_0 k v B_H}{R}}$

STOP

END OF EXAM

(e) No. on opposite side of the ring. the force is in opposite direction.

Name: ____________________________________

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

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