



AP[®] Physics C: Electricity and Magnetism 2013 Free-Response Questions

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TABLE OF INFORMATION DEVELOPED FOR 2012

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, $N_0 = 6.02 \times 10^{23} \text{ mol}^{-1}$	Universal gravitational constant, $G = 6.67 \times 10^{-11} \text{ m}^3/\text{kg}\cdot\text{s}^2$		
Universal gas constant, $R = 8.31 \text{ J}/(\text{mol}\cdot\text{K})$	Acceleration due to gravity at Earth's surface, $g = 9.8 \text{ m}/\text{s}^2$		
Boltzmann's constant, $k_B = 1.38 \times 10^{-23} \text{ J}/\text{K}$			
1 unified atomic mass unit,	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg} = 931 \text{ MeV}/c^2$		
Planck's constant,	$h = 6.63 \times 10^{-34} \text{ J}\cdot\text{s} = 4.14 \times 10^{-15} \text{ eV}\cdot\text{s}$		
	$hc = 1.99 \times 10^{-25} \text{ J}\cdot\text{m} = 1.24 \times 10^3 \text{ eV}\cdot\text{nm}$		
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{N}\cdot\text{m}^2$		
Coulomb's law constant, $k = 1/4\pi\epsilon_0 = 9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$			
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7} (\text{T}\cdot\text{m})/\text{A}$		
Magnetic constant, $k' = \mu_0/4\pi = 1 \times 10^{-7} (\text{T}\cdot\text{m})/\text{A}$			
1 atmosphere pressure,	$1 \text{ atm} = 1.0 \times 10^5 \text{ N}/\text{m}^2 = 1.0 \times 10^5 \text{ Pa}$		

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	$\sqrt{3}$	∞

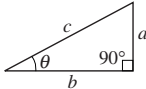
The following conventions are used in this exam.

- 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 DEVELOPED FOR 2012

MECHANICS	ELECTRICITY AND MAGNETISM
$v = v_0 + at$ $x = x_0 + v_0 t + \frac{1}{2}at^2$ $v^2 = v_0^2 + 2a(x - x_0)$ $\Sigma \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$ $\mathbf{F} = \frac{d\mathbf{p}}{dt}$ $\mathbf{J} = \int \mathbf{F} dt = \Delta \mathbf{p}$ $\mathbf{p} = m\mathbf{v}$ $F_{fric} \leq \mu N$ $W = \int \mathbf{F} \cdot d\mathbf{r}$ $K = \frac{1}{2}mv^2$ $P = \frac{dW}{dt}$ $P = \mathbf{F} \cdot \mathbf{v}$ $\Delta U_g = mgh$ $a_c = \frac{v^2}{r} = \omega^2 r$ $\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$ $\Sigma \boldsymbol{\tau} = \boldsymbol{\tau}_{net} = I\boldsymbol{\alpha}$ $I = \int r^2 dm = \Sigma mr^2$ $\mathbf{r}_{cm} = \Sigma m\mathbf{r} / \Sigma m$ $v = r\omega$ $\mathbf{L} = \mathbf{r} \times \mathbf{p} = I\boldsymbol{\omega}$ $K = \frac{1}{2}I\omega^2$ $\omega = \omega_0 + \alpha t$ $\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$	$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$ $\mathbf{E} = \frac{\mathbf{F}}{q}$ $\oint \mathbf{E} \cdot d\mathbf{A} = \frac{Q}{\epsilon_0}$ $E = -\frac{dV}{dr}$ $V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$ $U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$ $C = \frac{Q}{V}$ $C = \frac{\kappa\epsilon_0 A}{d}$ $C_p = \sum_i C_i$ $\frac{1}{C_s} = \sum_i \frac{1}{C_i}$ $I = \frac{dQ}{dt}$ $U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$ $R = \frac{\rho\ell}{A}$ $\mathbf{E} = \rho\mathbf{J}$ $I = Nev_d A$ $V = IR$ $R_s = \sum_i R_i$ $\frac{1}{R_p} = \sum_i \frac{1}{R_i}$ $P = IV$ $\mathbf{F}_M = q\mathbf{v} \times \mathbf{B}$
$a = \text{acceleration}$ $F = \text{force}$ $f = \text{frequency}$ $h = \text{height}$ $I = \text{rotational inertia}$ $J = \text{impulse}$ $K = \text{kinetic energy}$ $k = \text{spring constant}$ $\ell = \text{length}$ $L = \text{angular momentum}$ $m = \text{mass}$ $N = \text{normal force}$ $P = \text{power}$ $p = \text{momentum}$ $r = \text{radius or distance}$ $\mathbf{r} = \text{position vector}$ $T = \text{period}$ $t = \text{time}$ $U = \text{potential energy}$ $v = \text{velocity or speed}$ $W = \text{work done on a system}$ $x = \text{position}$ $\mu = \text{coefficient of friction}$ $\theta = \text{angle}$ $\tau = \text{torque}$ $\omega = \text{angular speed}$ $\alpha = \text{angular acceleration}$ $\phi = \text{phase angle}$	$A = \text{area}$ $B = \text{magnetic field}$ $C = \text{capacitance}$ $d = \text{distance}$ $E = \text{electric field}$ $\mathcal{E} = \text{emf}$ $F = \text{force}$ $I = \text{current}$ $J = \text{current density}$ $L = \text{inductance}$ $\ell = \text{length}$ $n = \text{number of loops of wire per unit length}$ $N = \text{number of charge carriers per unit volume}$ $P = \text{power}$ $Q = \text{charge}$ $q = \text{point charge}$ $R = \text{resistance}$ $r = \text{distance}$ $t = \text{time}$ $U = \text{potential or stored energy}$ $V = \text{electric potential}$ $v = \text{velocity or speed}$ $\rho = \text{resistivity}$ $\phi_m = \text{magnetic flux}$ $\kappa = \text{dielectric constant}$

ADVANCED PLACEMENT PHYSICS C EQUATIONS DEVELOPED FOR 2012

GEOMETRY AND TRIGONOMETRY	CALCULUS
Rectangle $A = bh$ Triangle $A = \frac{1}{2}bh$ Circle $A = \pi r^2$ $C = 2\pi r$ Rectangular Solid $V = \ell wh$ Cylinder $V = \pi r^2 \ell$ $S = 2\pi r \ell + 2\pi r^2$ Sphere $V = \frac{4}{3}\pi r^3$ $S = 4\pi r^2$ Right Triangle $a^2 + b^2 = c^2$ $\sin \theta = \frac{a}{c}$ $\cos \theta = \frac{b}{c}$ $\tan \theta = \frac{a}{b}$ 	$\frac{df}{dx} = \frac{df}{du} \frac{du}{dx}$ $\frac{d}{dx}(x^n) = nx^{n-1}$ $\frac{d}{dx}(e^x) = e^x$ $\frac{d}{dx}(\ln x) = \frac{1}{x}$ $\frac{d}{dx}(\sin x) = \cos x$ $\frac{d}{dx}(\cos x) = -\sin x$ $\int x^n dx = \frac{1}{n+1}x^{n+1}, n \neq -1$ $\int e^x dx = e^x$ $\int \frac{dx}{x} = \ln x $ $\int \cos x dx = \sin x$ $\int \sin x dx = -\cos x$

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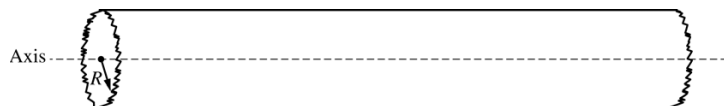
PHYSICS C: ELECTRICITY AND MAGNETISM

SECTION II

Time—45 minutes

3 Questions

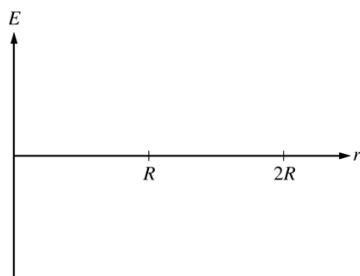
Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



E&M 1.

A very long, solid, nonconducting cylinder of radius R has a positive charge of uniform volume density ρ . A section of the cylinder far from its ends is shown in the diagram above. Let r represent the radial distance from the axis of the cylinder. Express all answers in terms of r , R , ρ , and fundamental constants, as appropriate.

- Using Gauss's law, derive an expression for the magnitude of the electric field at a radius $r < R$. Draw an appropriate Gaussian surface on the diagram.
- Using Gauss's law, derive an expression for the magnitude of the electric field at a radius $r > R$.
- On the axes below, sketch the graph of electric field E as a function of radial distance r for $r = 0$ to $r = 2R$. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.



(d)

i. Derive an expression for the magnitude of the potential difference between $r = 0$ and $r = R$.

ii. Is the potential higher at $r = 0$ or $r = R$?

_____ $r = 0$ _____ $r = R$

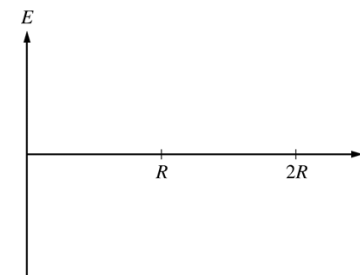
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- The nonconducting cylinder is replaced with a conducting cylinder of the same shape and same linear charge density. On the axes below, sketch the electric field E as a function of r for $r = 0$ to $r = 2R$. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.

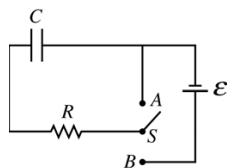


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E&M 2.

In a lab, you set up a circuit that contains a capacitor C , a resistor R , a switch S , and a power supply, as shown in the diagram above. The capacitor is initially uncharged. The switch, which is initially open, can be moved to positions A or B .

(a)

- i. Indicate the position to which the switch should be moved to charge the capacitor.

___ A ___ B

- ii. On the diagram, draw a voltmeter that is properly connected to the circuit in a manner that will allow the voltage to be measured across the capacitor.

After a long time you move the switch to discharge the capacitor, and your lab partner starts a stopwatch. You collect the following measurements of the voltage across the capacitor at various times.

t (s)	6	18	30	42	54
V (V)	252	74	33	10	6

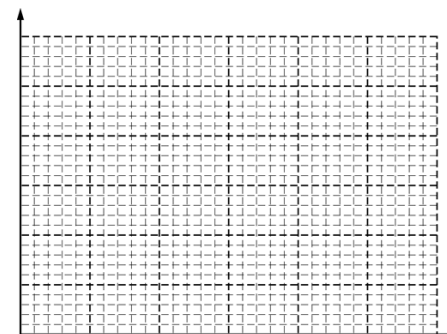
You wish to determine the time constant τ of the circuit from the slope of a linear graph.

(b)

- i. Indicate two quantities you would plot to obtain a linear graph.
- ii. Use the remaining rows in the table above, as needed, to record any quantities that you indicated that are not given. Label each row you use and include units.

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- (c) On the axes below, graph the data from the table that will produce a linear relationship. Clearly scale and label all axes including units, if appropriate. Draw a straight line that best fits your data points.

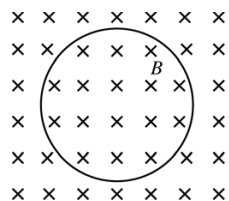


- (d) From your line in part (c), obtain the value of the time constant τ of the circuit.

(e)

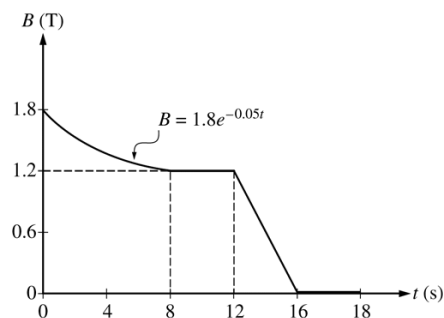
- i. In the experiment, the capacitor C had a capacitance of $1.50 \mu\text{F}$. Calculate an experimental value for the resistance R .
- ii. On the axes in part (c), use a dashed line to sketch a possible graph if the capacitance was greater than $1.50 \mu\text{F}$ but the resistance R was the same. Justify your answer.

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E&M 3.

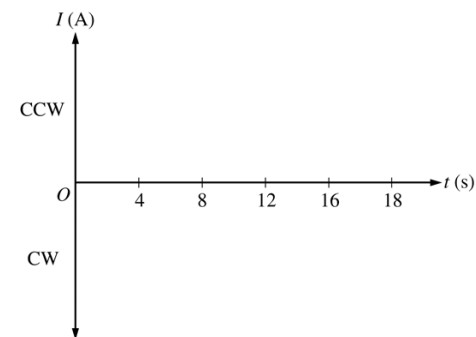
The figure above shows a circular loop of area 0.25 m^2 and resistance 12Ω that lies in the plane of the page. A magnetic field of magnitude B directed into the page exists in the area of the loop. The field varies with time t , as shown in the graph below.



- (a)
- Derive an expression for the magnitude of the induced emf in the loop as a function of time for the interval $t = 0$ s to $t = 8$ s.
 - Calculate the magnitude of the induced current I in the loop at time $t = 4$ s.

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- (b)
- Sketch a graph of the induced current I in the loop as a function of time t from $t = 0$ s to $t = 18$ s on the axes below, assuming that a counterclockwise (CCW) current is positive.



- For the time interval 12 s to 16 s, justify the direction of the current you have indicated in your graph.
- (c) Calculate the total energy dissipated in the loop during the first 8 s shown.

STOP
END OF EXAM