



AP[®] Physics C: Electricity and Magnetism 2010 Free-Response Questions

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TABLE OF INFORMATION FOR 2010 and 2011

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

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	$4/3$	$\sqrt{3}$	∞

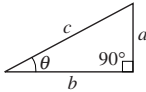
The following conventions are used in this exam.

- 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 FOR 2010 and 2011

MECHANICS	ELECTRICITY AND MAGNETISM
$v = v_0 + at$ $x = x_0 + v_0 t + \frac{1}{2}at^2$ $v^2 = v_0^2 + 2a(x - x_0)$ $\Sigma \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$ $\mathbf{F} = \frac{d\mathbf{p}}{dt}$ $\mathbf{J} = \int \mathbf{F} dt = \Delta \mathbf{p}$ $\mathbf{p} = m\mathbf{v}$ $F_{fric} \leq \mu N$ $W = \int \mathbf{F} \cdot d\mathbf{r}$ $K = \frac{1}{2}mv^2$ $P = \frac{dW}{dt}$ $P = \mathbf{F} \cdot \mathbf{v}$ $\Delta U_g = mgh$ $a_c = \frac{v^2}{r} = \omega^2 r$ $\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$ $\Sigma \boldsymbol{\tau} = \boldsymbol{\tau}_{net} = I\boldsymbol{\alpha}$ $I = \int r^2 dm = \Sigma mr^2$ $\mathbf{r}_{cm} = \Sigma m\mathbf{r} / \Sigma m$ $v = r\omega$ $\mathbf{L} = \mathbf{r} \times \mathbf{p} = I\boldsymbol{\omega}$ $K = \frac{1}{2}I\omega^2$ $\omega = \omega_0 + \alpha t$ $\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$	$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$ $\mathbf{E} = \frac{\mathbf{F}}{q}$ $\oint \mathbf{E} \cdot d\mathbf{A} = \frac{Q}{\epsilon_0}$ $E = -\frac{dV}{dr}$ $V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$ $U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$ $C = \frac{Q}{V}$ $C = \frac{\kappa\epsilon_0 A}{d}$ $C_p = \sum_i C_i$ $\frac{1}{C_s} = \sum_i \frac{1}{C_i}$ $I = \frac{dQ}{dt}$ $U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$ $R = \frac{\rho\ell}{A}$ $\mathbf{E} = \rho\mathbf{J}$ $I = Nev_d A$ $V = IR$ $R_s = \sum_i R_i$ $\frac{1}{R_p} = \sum_i \frac{1}{R_i}$ $P = IV$ $\mathbf{F}_M = q\mathbf{v} \times \mathbf{B}$ $A = \text{area}$ $B = \text{magnetic field}$ $C = \text{capacitance}$ $d = \text{distance}$ $\mathcal{E} = \text{emf}$ $F = \text{force}$ $I = \text{current}$ $J = \text{current density}$ $L = \text{inductance}$ $\ell = \text{length}$ $n = \text{number of loops of wire per unit length}$ $N = \text{number of charge carriers per unit volume}$ $P = \text{power}$ $Q = \text{charge}$ $R = \text{resistance}$ $r = \text{distance}$ $t = \text{time}$ $U = \text{potential or stored energy}$ $V = \text{electric potential}$ $v = \text{velocity or speed}$ $\rho = \text{resistivity}$ $\phi_m = \text{magnetic flux}$ $\kappa = \text{dielectric constant}$ $\oint \mathbf{B} \cdot d\boldsymbol{\ell} = \mu_0 I$ $d\mathbf{B} = \frac{\mu_0}{4\pi} \frac{I d\boldsymbol{\ell} \times \mathbf{r}}{r^3}$ $\mathbf{F} = \int I d\boldsymbol{\ell} \times \mathbf{B}$ $B_s = \mu_0 nI$ $\phi_m = \int \mathbf{B} \cdot d\mathbf{A}$ $\mathcal{E} = \oint \mathbf{E} \cdot d\boldsymbol{\ell} = -\frac{d\phi_m}{dt}$ $\mathcal{E} = -L \frac{dI}{dt}$ $U_L = \frac{1}{2}LI^2$

ADVANCED PLACEMENT PHYSICS C EQUATIONS FOR 2010 and 2011

GEOMETRY AND TRIGONOMETRY	CALCULUS
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 $a^2 + b^2 = c^2$ $\sin \theta = \frac{a}{c}$ $\cos \theta = \frac{b}{c}$ $\tan \theta = \frac{a}{b}$ 	$\frac{df}{dx} = \frac{df}{du} \frac{du}{dx}$ $\frac{d}{dx}(x^n) = nx^{n-1}$ $\frac{d}{dx}(e^x) = e^x$ $\frac{d}{dx}(\ln x) = \frac{1}{x}$ $\frac{d}{dx}(\sin x) = \cos x$ $\frac{d}{dx}(\cos x) = -\sin x$ $\int x^n dx = \frac{1}{n+1}x^{n+1}, n \neq -1$ $\int e^x dx = e^x$ $\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 the pink booklet in the spaces provided after each part, NOT in this green insert.

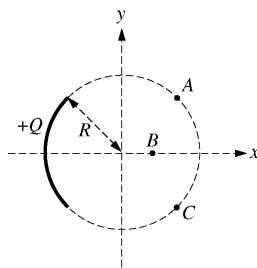


Figure I

E&M. 1.

A charge $+Q$ is uniformly distributed over a quarter circle of radius R , as shown above. Points A , B , and C are located as shown, with A and C located symmetrically relative to the x -axis. Express all algebraic answers in terms of the given quantities and fundamental constants.

- (a) Rank the magnitude of the electric potential at points A , B , and C from greatest to least, with number 1 being greatest. If two points have the same potential, give them the same ranking.

_____ V_A _____ V_B _____ V_C

Justify your rankings.

Point P is at the origin, as shown below, and is the center of curvature of the charge distribution.

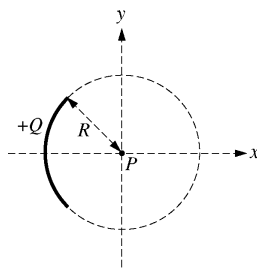


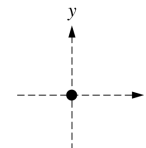
Figure II

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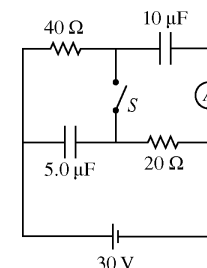
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- (b) Determine an expression for the electric potential at point P due to the charge Q .
- (c) A positive point charge q with mass m is placed at point P and released from rest. Derive an expression for the speed of the point charge when it is very far from the origin.
- (d) On the dot representing point P below, indicate the direction of the electric field at point P due to the charge Q .



- (e) Derive an expression for the magnitude of the electric field at point P .



E&M. 2.

In the circuit illustrated above, switch S is initially open and the battery has been connected for a long time.

- (a) What is the steady-state current through the ammeter?
- (b) Calculate the charge on the $10\ \mu\text{F}$ capacitor.
- (c) Calculate the energy stored in the $5.0\ \mu\text{F}$ capacitor.

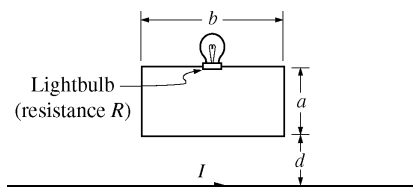
The switch is now closed, and the circuit comes to a new steady state.

- (d) Calculate the steady-state current through the battery.
- (e) Calculate the final charge on the $5.0\ \mu\text{F}$ capacitor.
- (f) Calculate the energy dissipated as heat in the $40\ \Omega$ resistor in one minute once the circuit has reached steady state.

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E&M. 3.

The long straight wire illustrated above carries a current I to the right. The current varies with time t according to the equation $I = I_0 - Kt$, where I_0 and K are positive constants and I remains positive throughout the time period of interest. The bottom of a rectangular loop of wire of width b and height a is located a distance d above the long wire, with the long wire in the plane of the loop as shown. A lightbulb with resistance R is connected in the loop. Express all algebraic answers in terms of the given quantities and fundamental constants.

(a) Indicate the direction of the current in the loop.

___ Clockwise ___ Counterclockwise

Justify your answer.

(b) Indicate whether the lightbulb gets brighter, gets dimmer, or stays the same brightness over the time period of interest.

___ Gets brighter ___ Gets dimmer ___ Remains the same

Justify your answer.

(c) Determine the magnetic field at $t = 0$ due to the current in the long wire at distance r from the long wire.

(d) Derive an expression for the magnetic flux through the loop as a function of time.

(e) Derive an expression for the power dissipated by the lightbulb.

END OF EXAM