



AP[®] Physics C: Electricity and Magnetism 2008 Free-Response Questions

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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 = 4.14×10^{-15} eV·s	
	$hc = 1.99 \times 10^{-25}$ J·m = 1.24×10^3 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 = 1.0×10^5 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	$\sqrt{3}$	∞

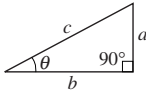
The following conventions are used in this exam.

- 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	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 = 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	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

ADVANCED PLACEMENT PHYSICS C EQUATIONS FOR 2008 and 2009

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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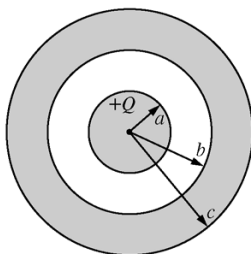
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SECTION II

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.



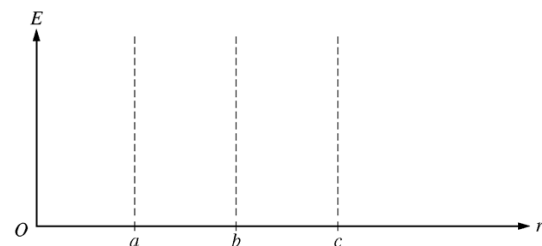
E&M. 1.

A metal sphere of radius a contains a charge $+Q$ and is surrounded by an uncharged, concentric, metallic shell of inner radius b and outer radius c , as shown above. Express all algebraic answers in terms of the given quantities and fundamental constants.

- (a) Determine the induced charge on each of the following and explain your reasoning in each case.
 - i. The inner surface of the metallic shell
 - ii. The outer surface of the metallic shell
- (b) Determine expressions for the magnitude of the electric field E as a function of r , the distance from the center of the inner sphere, in each of the following regions.
 - i. $r < a$
 - ii. $a < r < b$
 - iii. $b < r < c$
 - iv. $c < r$

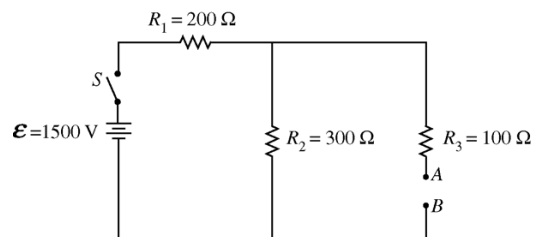
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- (c) On the axes below, sketch a graph of E as a function of r .



- (d) An electron of mass m_e carrying a charge $-e$ is released from rest at a very large distance from the spheres. Derive an expression for the speed of the particle at a distance $10r$ from the center of the spheres.

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E&M. 2.

In the circuit shown above, A and B are terminals to which different circuit components can be connected.

- (a) Calculate the potential difference across R_2 immediately after the switch S is closed in each of the following cases.
- A $50\ \Omega$ resistor connects A and B .
 - A 40 mH inductor connects A and B .
 - An initially uncharged $0.80\ \mu\text{F}$ capacitor connects A and B .
- (b) The switch gets closed at time $t = 0$. On the axes below, sketch the graphs of the current in the $100\ \Omega$ resistor R_3 versus time t for the three cases. Label the graphs R for the resistor, L for the inductor, and C for the capacitor.



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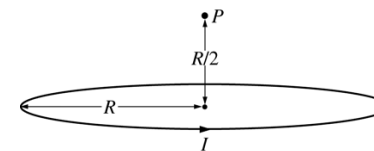


Figure 1

E&M. 3.

The circular loop of wire in Figure 1 above has a radius of R and carries a current I . Point P is a distance of $R/2$ above the center of the loop. Express algebraic answers to parts (a) and (b) in terms of R , I , and fundamental constants.

- (a)
- State the direction of the magnetic field B_1 at point P due to the current in the loop.
 - Calculate the magnitude of the magnetic field B_1 at point P .

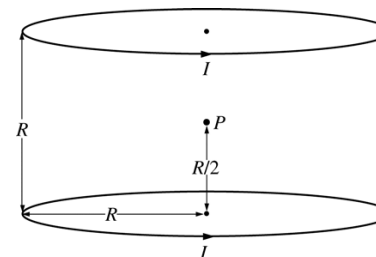


Figure 2

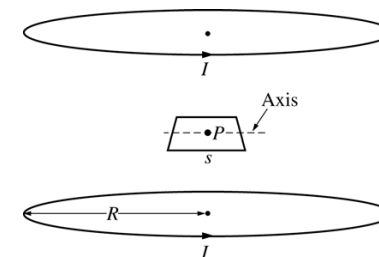


Figure 3

A second identical loop also carrying a current I is added at a distance of R above the first loop, as shown in Figure 2 above.

- (b) Determine the magnitude of the net magnetic field B_{net} at point P .

A small square loop of wire in which each side has a length s is now placed at point P with its plane parallel to the plane of each loop, as shown in Figure 3 above. For parts (c) and (d), assume that the magnetic field between the two circular loops is uniform in the region of the square loop and has magnitude B_{net} .

- (c) In terms of B_{net} and s , determine the magnetic flux through the square loop.
- (d) The square loop is now rotated about an axis in its plane at an angular speed ω . In terms of B_{net} , s , and ω , calculate the induced emf in the loop as a function of time t , assuming that the loop is horizontal at $t = 0$.

END OF EXAM