



AP[®] Physics C: Electricity and Magnetism 2004 Free-Response Questions

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TABLE OF INFORMATION FOR 2004 and 2005

CONSTANTS AND CONVERSION FACTORS		UNITS		PREFIXES			
		Name	Symbol	Factor	Prefix	Symbol	
1 unified atomic mass unit,	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$ $= 931 \text{ MeV}/c^2$	meter	m	10^9	giga	G	
Proton mass,	$m_p = 1.67 \times 10^{-27} \text{ kg}$	kilogram	kg	10^6	mega	M	
Neutron mass,	$m_n = 1.67 \times 10^{-27} \text{ kg}$	second	s	10^3	kilo	k	
Electron mass,	$m_e = 9.11 \times 10^{-31} \text{ kg}$	ampere	A	10^{-2}	centi	c	
Magnitude of the electron charge,	$e = 1.60 \times 10^{-19} \text{ C}$	kelvin	K	10^{-3}	milli	m	
Avogadro's number,	$N_0 = 6.02 \times 10^{23} \text{ mol}^{-1}$	mole	mol	10^{-6}	micro	μ	
Universal gas constant,	$R = 8.31 \text{ J}/(\text{mol} \cdot \text{K})$	hertz	Hz	10^{-9}	nano	n	
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23} \text{ J/K}$	newton	N	10^{-12}	pico	p	
Speed of light,	$c = 3.00 \times 10^8 \text{ m/s}$	pascal	Pa	VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES			
Planck's constant,	$h = 6.63 \times 10^{-34} \text{ J} \cdot \text{s}$ $= 4.14 \times 10^{-15} \text{ eV} \cdot \text{s}$	joule	J				
	$hc = 1.99 \times 10^{-25} \text{ J} \cdot \text{m}$ $= 1.24 \times 10^3 \text{ eV} \cdot \text{nm}$	watt	W				
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2$	coulomb	C				
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$	volt	V				
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7} (\text{T} \cdot \text{m})/\text{A}$	ohm	Ω				
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7} (\text{T} \cdot \text{m})/\text{A}$	henry	H				
Universal gravitational constant,	$G = 6.67 \times 10^{-11} \text{ m}^3/\text{kg} \cdot \text{s}^2$	farad	F				
Acceleration due to gravity at the Earth's surface,	$g = 9.8 \text{ m/s}^2$	tesla	T				
1 atmosphere pressure,	$1 \text{ atm} = 1.0 \times 10^5 \text{ N/m}^2$ $= 1.0 \times 10^5 \text{ Pa}$	degree Celsius	$^\circ\text{C}$				
1 electron volt,	$1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$	electron-volt	eV				
				θ	$\sin \theta$	$\cos \theta$	$\tan \theta$
				0°	0	1	0
				30°	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
				37°	3/5	4/5	3/4
				45°	$\sqrt{2}/2$	$\sqrt{2}/2$	1
				53°	4/5	3/5	4/3
				60°	$\sqrt{3}/2$	1/2	$\sqrt{3}$
				90°	1	0	∞

The following conventions are used in this examination.

- 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 2004 and 2005

MECHANICS

$v = v_0 + at$	$a = \text{acceleration}$
$x = x_0 + v_0t + \frac{1}{2}at^2$	$F = \text{force}$
$v^2 = v_0^2 + 2a(x - x_0)$	$f = \text{frequency}$
$\Sigma \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$	$h = \text{height}$
$\mathbf{F} = \frac{d\mathbf{p}}{dt}$	$I = \text{rotational inertia}$
$\mathbf{J} = \int \mathbf{F} dt = \Delta \mathbf{p}$	$J = \text{impulse}$
$\mathbf{p} = m\mathbf{v}$	$K = \text{kinetic energy}$
$F_{fric} \leq \mu N$	$k = \text{spring constant}$
$W = \int \mathbf{F} \cdot d\mathbf{r}$	$\ell = \text{length}$
$K = \frac{1}{2}mv^2$	$L = \text{angular momentum}$
$P = \frac{dW}{dt}$	$m = \text{mass}$
$P = \mathbf{F} \cdot \mathbf{v}$	$N = \text{normal force}$
$\Delta U_g = mgh$	$P = \text{power}$
$a_c = \frac{v^2}{r} = \omega^2 r$	$p = \text{momentum}$
$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$	$r = \text{radius or distance}$
$\Sigma \boldsymbol{\tau} = \boldsymbol{\tau}_{net} = I\boldsymbol{\alpha}$	$\mathbf{r} = \text{position vector}$
$I = \int r^2 dm = \Sigma mr^2$	$T = \text{period}$
$\mathbf{r}_{cm} = \Sigma m\mathbf{r} / \Sigma m$	$t = \text{time}$
$v = r\omega$	$U = \text{potential energy}$
$\mathbf{L} = \mathbf{r} \times \mathbf{p} = I\boldsymbol{\omega}$	$v = \text{velocity or speed}$
$K = \frac{1}{2}I\omega^2$	$W = \text{work done on a system}$
$\omega = \omega_0 + \alpha t$	$x = \text{position}$
$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$	$\mu = \text{coefficient of friction}$
$\mathbf{F}_s = -k\mathbf{x}$	$\theta = \text{angle}$
$U_s = \frac{1}{2}kx^2$	$\tau = \text{torque}$
$T = \frac{2\pi}{\omega} = \frac{1}{f}$	$\omega = \text{angular speed}$
$T_s = 2\pi\sqrt{\frac{m}{k}}$	$\alpha = \text{angular acceleration}$
$T_p = 2\pi\sqrt{\frac{\ell}{g}}$	
$\mathbf{F}_G = -\frac{Gm_1m_2}{r^2}\hat{\mathbf{r}}$	
$U_G = -\frac{Gm_1m_2}{r}$	

ELECTRICITY AND MAGNETISM

$F = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r^2}$	$A = \text{area}$
$\mathbf{E} = \frac{\mathbf{F}}{q}$	$B = \text{magnetic field}$
$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{Q}{\epsilon_0}$	$C = \text{capacitance}$
$E = -\frac{dV}{dr}$	$d = \text{distance}$
$V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$	$E = \text{electric field}$
$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r}$	$\mathcal{E} = \text{emf}$
$C = \frac{Q}{V}$	$F = \text{force}$
$C = \frac{\kappa\epsilon_0 A}{d}$	$I = \text{current}$
$C_p = \sum_i C_i$	$L = \text{inductance}$
$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$	$\ell = \text{length}$
$I = \frac{dQ}{dt}$	$n = \text{number of loops of wire per unit length}$
$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$	$P = \text{power}$
$R = \frac{\rho\ell}{A}$	$Q = \text{charge}$
$V = IR$	$q = \text{point charge}$
$R_s = \sum_i R_i$	$R = \text{resistance}$
$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$	$r = \text{distance}$
$P = IV$	$t = \text{time}$
$\mathbf{F}_M = q\mathbf{v} \times \mathbf{B}$	$U = \text{potential or stored energy}$
$\oint \mathbf{B} \cdot d\boldsymbol{\ell} = \mu_0 I$	$V = \text{electric potential}$
$\mathbf{F} = \int I d\boldsymbol{\ell} \times \mathbf{B}$	$v = \text{velocity or speed}$
$B_s = \mu_0 nI$	$\rho = \text{resistivity}$
$\phi_m = \int \mathbf{B} \cdot d\mathbf{A}$	$\phi_m = \text{magnetic flux}$
$\mathcal{E} = -\frac{d\phi_m}{dt}$	$\kappa = \text{dielectric constant}$
$\mathcal{E} = -L\frac{dI}{dt}$	
$U_L = \frac{1}{2}LI^2$	

ADVANCED PLACEMENT PHYSICS C EQUATIONS FOR 2004 and 2005

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

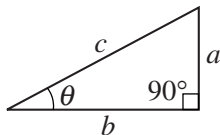
$$a^2 + b^2 = c^2$$

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

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

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

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



CALCULUS

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

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

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

$$\frac{d}{dx}(\ln x) = \frac{1}{x}$$

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

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

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

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

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

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

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

**2004 AP[®] PHYSICS C: ELECTRICITY AND MAGNETISM
FREE-RESPONSE QUESTIONS**

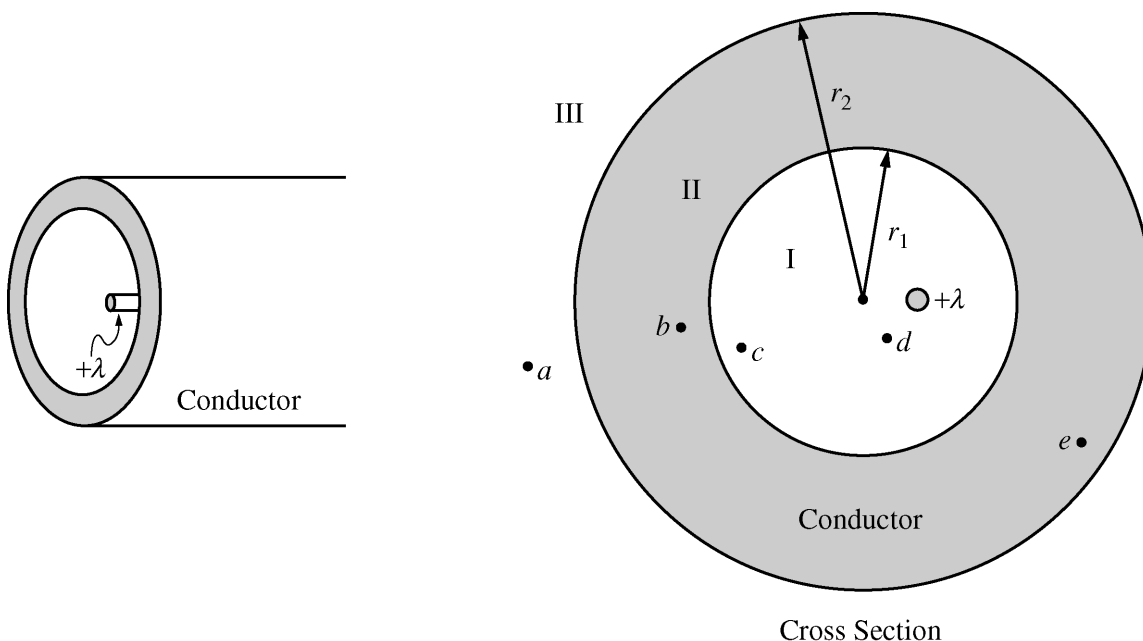
PHYSICS C

Section II, ELECTRICITY AND MAGNETISM

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 booklet in the spaces provided after each part, NOT in this green insert.



E&M. 1.

The figure above left shows a hollow, infinite, cylindrical, uncharged conducting shell of inner radius r_1 and outer radius r_2 . An infinite line charge of linear charge density $+\lambda$ is parallel to its axis but off center. An enlarged cross section of the cylindrical shell is shown above right.

(a) On the cross section above right,

- i. sketch the electric field lines, if any, in each of regions I, II, and III and
- ii. use + and - signs to indicate any charge induced on the conductor.

(b) In the spaces below, rank the electric potentials at points a , b , c , d , and e from highest to lowest (1 = highest potential). If two points are at the same potential, give them the same number.

_____ V_a

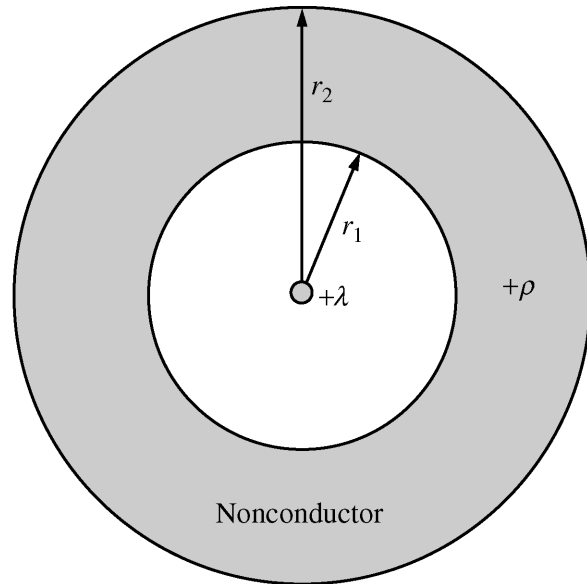
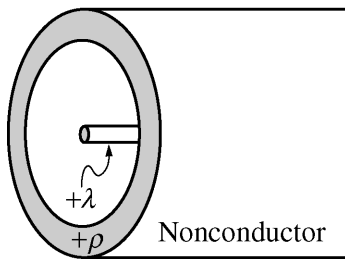
_____ V_b

_____ V_c

_____ V_d

_____ V_e

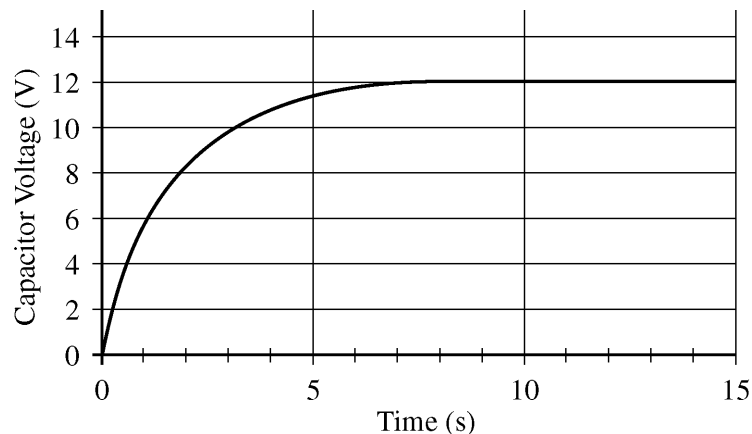
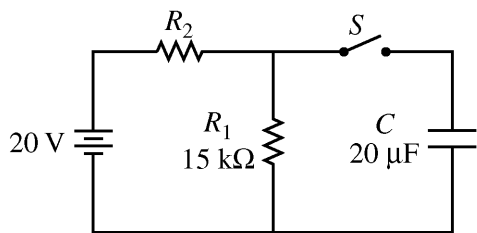
2004 AP[®] PHYSICS C: ELECTRICITY AND MAGNETISM
FREE-RESPONSE QUESTIONS



Cross Section

- (c) The shell is replaced by another cylindrical shell that has the same dimensions but is nonconducting and carries a uniform volume charge density $+\rho$. The infinite line charge, still of charge density $+\lambda$, is located at the center of the shell as shown above. Using Gauss's law, calculate the magnitude of the electric field as a function of the distance r from the center of the shell for each of the following regions. Express your answers in terms of the given quantities and fundamental constants.
- $r < r_1$
 - $r_1 \leq r \leq r_2$
 - $r > r_2$

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FREE-RESPONSE QUESTIONS



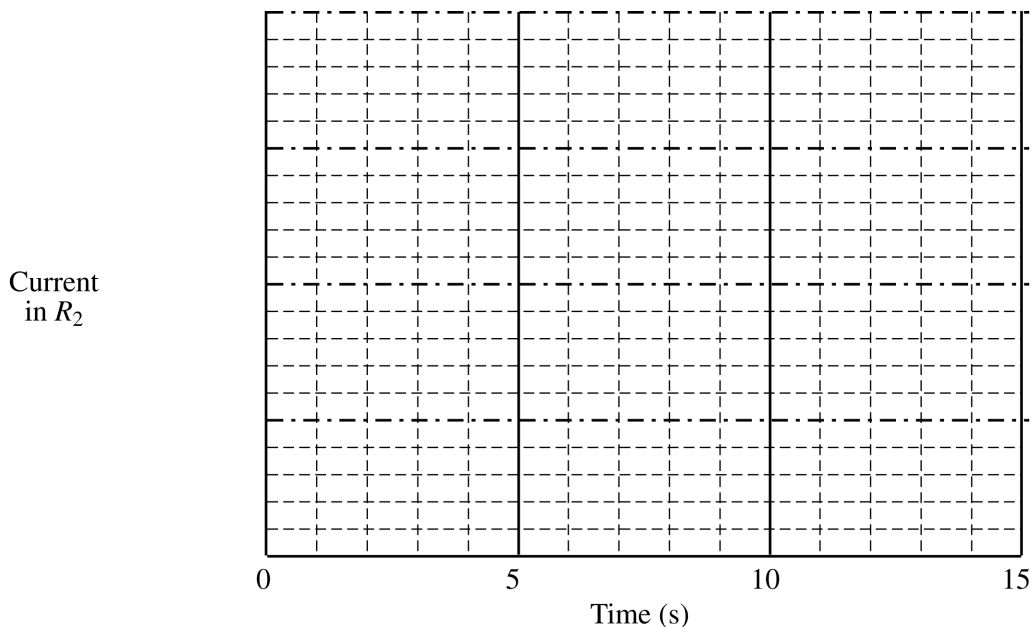
E&M. 2.

In the circuit shown above left, the switch S is initially in the open position and the capacitor C is initially uncharged. A voltage probe and a computer (not shown) are used to measure the potential difference across the capacitor as a function of time after the switch is closed. The graph produced by the computer is shown above right. The battery has an emf of 20 V and negligible internal resistance. Resistor R_1 has a resistance of $15\text{ k}\Omega$ and the capacitor C has a capacitance of $20\text{ }\mu\text{F}$.

- Determine the voltage across resistor R_2 immediately after the switch is closed.
- Determine the voltage across resistor R_2 a long time after the switch is closed.
- Calculate the value of the resistor R_2 .
- Calculate the energy stored in the capacitor a long time after the switch is closed.

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FREE-RESPONSE QUESTIONS

- (e) On the axes below, graph the current in R_2 as a function of time from 0 to 15 s. Label the vertical axis with appropriate values.



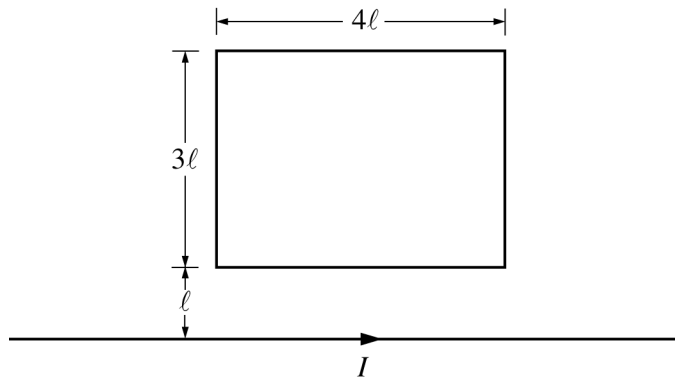
Resistor R_2 is removed and replaced with another resistor of lesser resistance. Switch S remains closed for a long time.

- (f) Indicate below whether the energy stored in the capacitor is greater than, less than, or the same as it was with resistor R_2 in the circuit.

Greater than Less than The same as

Explain your reasoning.

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FREE-RESPONSE QUESTIONS



E&M. 3.

A rectangular loop of dimensions 3ℓ and 4ℓ lies in the plane of the page as shown above. A long straight wire also in the plane of the page carries a current I .

(a) Calculate the magnetic flux through the rectangular loop in terms of I , ℓ , and fundamental constants.

Starting at time $t = 0$, the current in the long straight wire is given as a function of time t by

$$I(t) = I_0 e^{-kt}, \text{ where } I_0 \text{ and } k \text{ are constants.}$$

(b) The current induced in the loop is in which direction?

_____ Clockwise _____ Counterclockwise

Justify your answer.

The loop has a resistance R . Calculate each of the following in terms of R , I_0 , k , ℓ , and fundamental constants.

(c) The current in the loop as a function of time t

(d) The total energy dissipated in the loop from $t = 0$ to $t = \infty$

END OF SECTION II, ELECTRICITY AND MAGNETISM