



AP[®] Physics C: Electricity and Magnetism 2002 Free-Response Questions

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TABLE OF INFORMATION FOR 2002

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 2002

MECHANICS

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

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

ADVANCED PLACEMENT PHYSICS C EQUATIONS FOR 2002

GEOMETRY AND TRIGONOMETRY

Rectangle	A = area
$A = bh$	C = circumference
Triangle	V = volume
$A = \frac{1}{2}bh$	S = surface area
Circle	b = base
$A = \pi r^2$	h = height
$C = 2\pi r$	ℓ = length
Parallelepiped	w = width
$V = \ell wh$	r = radius

Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r \ell + 2\pi r^2$

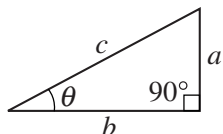
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

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

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

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

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



CALCULUS

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

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

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

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

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

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

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

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

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

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

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

**2002 AP[®] PHYSICS C: ELECTRICITY AND MAGNETISM
FREE-RESPONSE QUESTIONS**

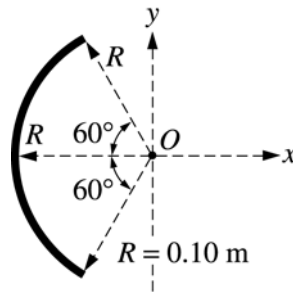
PHYSICS C

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



E&M 1.

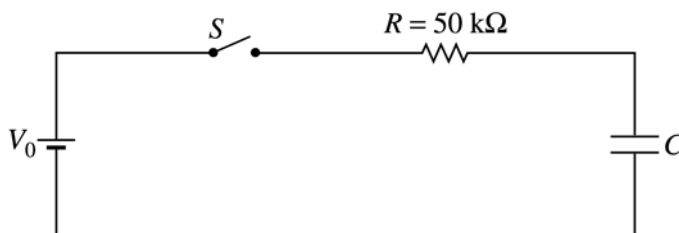
A rod of uniform linear charge density $\lambda = +1.5 \times 10^{-5} \text{ C/m}$ is bent into an arc of radius $R = 0.10 \text{ m}$. The arc is placed with its center at the origin of the axes shown above.

- (a) Determine the total charge on the rod.
- (b) Determine the magnitude and direction of the electric field at the center O of the arc.
- (c) Determine the electric potential at point O .

A proton is now placed at point O and held in place. Ignore the effects of gravity in the rest of this problem.

- (d) Determine the magnitude and direction of the force that must be applied in order to keep the proton at rest.
- (e) The proton is now released. Describe in words its motion for a long time after its release.

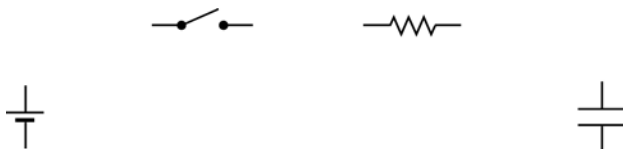
**2002 AP[®] PHYSICS C: ELECTRICITY AND MAGNETISM
FREE-RESPONSE QUESTIONS**



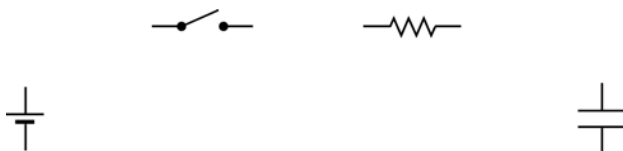
E&M 2.

Your engineering firm has built the RC circuit shown above. The current is measured for the time t after the switch is closed at $t = 0$ and the best-fit curve is represented by the equation $I(t) = 5.20 e^{-t/10}$, where I is in milliamperes and t is in seconds.

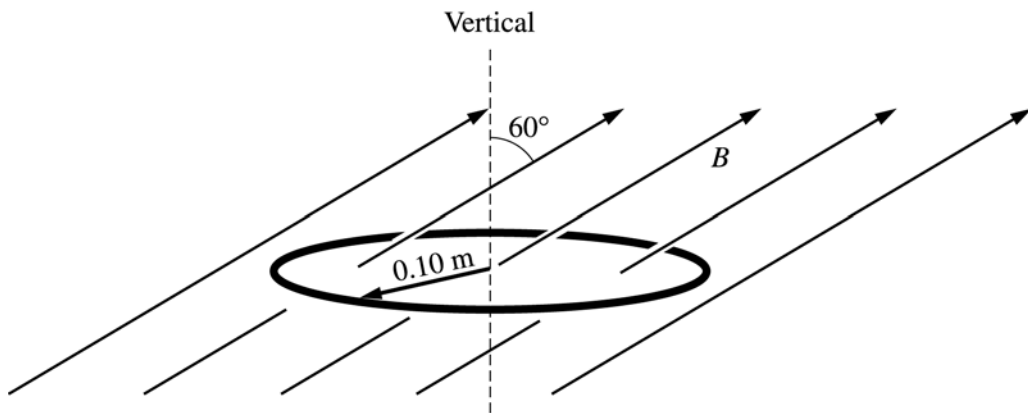
- (a) Determine the value of the charging voltage V_0 predicted by the equation.
- (b) Determine the value of the capacitance C predicted by the equation.
- (c) The charging voltage is measured in the laboratory and found to be greater than predicted in part (a).
 - i. Give one possible explanation for this finding.
 - ii. Explain the implications that your answer to part i has for the predicted value of the capacitance.
- (d) Your laboratory supervisor tells you that the charging time must be decreased. You may add resistors or capacitors to the original components and reconnect the RC circuit. In parts i and ii below, show how to reconnect the circuit, using either an additional resistor or a capacitor to decrease the charging time.
 - i. Indicate how a resistor may be added to decrease the charging time. Add the necessary resistor and connections to the following diagram.



- ii. Instead of a resistor, use a capacitor. Indicate how the capacitor may be added to decrease the charging time. Add the necessary capacitor and connections to the following diagram.



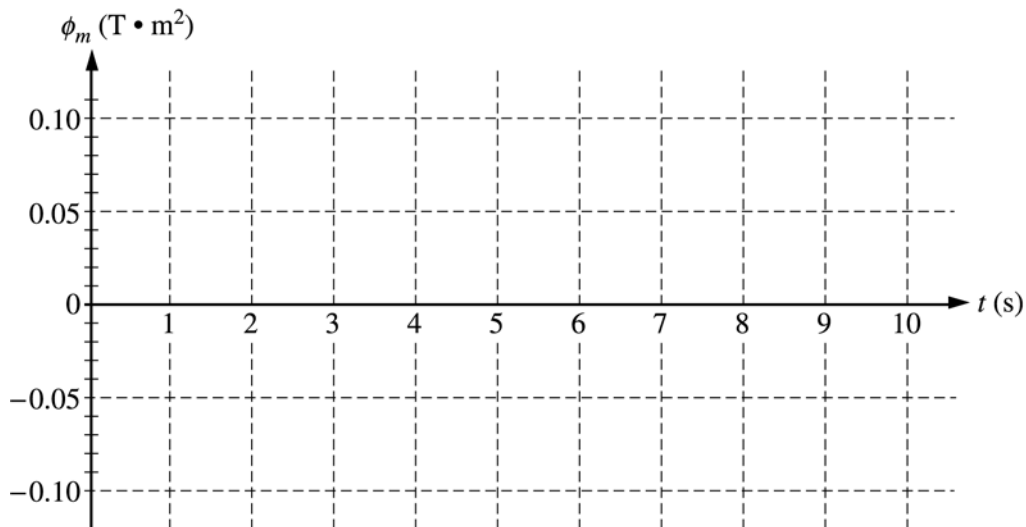
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FREE-RESPONSE QUESTIONS**



E&M 3.

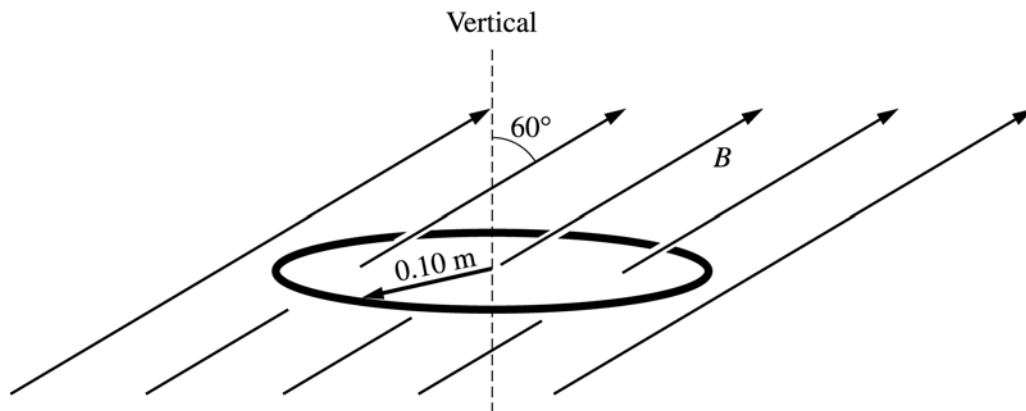
A circular wire loop with radius 0.10 m and resistance 50Ω is suspended horizontally in a magnetic field of magnitude B directed upward at an angle of 60° with the vertical, as shown above. The magnitude of the field in teslas is given as a function of time t in seconds by the equation $B = 4(1 - 0.2t)$.

- Determine the magnetic flux ϕ_m through the loop as a function of time.
- Graph the magnetic flux ϕ_m as a function of time on the axes below.



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FREE-RESPONSE QUESTIONS**

- (c) Determine the magnitude of the induced emf in the loop.
- (d) i. Determine the magnitude of the induced current in the loop.
ii. Show the direction of the induced current on the following diagram.



- (e) Determine the energy dissipated in the loop from $t = 0$ to $t = 4\text{ s}$.

END OF SECTION II, ELECTRICITY AND MAGNETISM