



## AP<sup>®</sup> 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	$\mu$	
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	$\Omega$				
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				
				$\theta$	$\sin \theta$	$\cos \theta$	$\tan \theta$
				$0^\circ$	0	1	0
				$30^\circ$	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
				$37^\circ$	3/5	4/5	3/4
				$45^\circ$	$\sqrt{2}/2$	$\sqrt{2}/2$	1
				$53^\circ$	4/5	3/5	4/3
				$60^\circ$	$\sqrt{3}/2$	1/2	$\sqrt{3}$
				$90^\circ$	1	0	$\infty$

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**

$$v = v_0 + at$$

$$x = x_0 + v_0t + \frac{1}{2}at^2$$

$$v^2 = v_0^2 + 2a(x - x_0)$$

$$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$$

$$\mathbf{F} = \frac{d\mathbf{p}}{dt}$$

$$\mathbf{J} = \int \mathbf{F} dt = \Delta\mathbf{p}$$

$$\mathbf{p} = m\mathbf{v}$$

$$F_{fric} \leq \mu N$$

$$W = \int \mathbf{F} \cdot d\mathbf{r}$$

$$K = \frac{1}{2}mv^2$$

$$P = \frac{dW}{dt}$$

$$P = \mathbf{F} \cdot \mathbf{v}$$

$$\Delta U_g = mgh$$

$$a_c = \frac{v^2}{r} = \omega^2 r$$

$$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$$

$$\sum \boldsymbol{\tau} = \boldsymbol{\tau}_{net} = I\boldsymbol{\alpha}$$

$$I = \int r^2 dm = \sum mr^2$$

$$\mathbf{r}_{cm} = \sum m\mathbf{r} / \sum m$$

$$v = r\omega$$

$$\mathbf{L} = \mathbf{r} \times \mathbf{p} = I\boldsymbol{\omega}$$

$$K = \frac{1}{2}I\omega^2$$

$$\omega = \omega_0 + \alpha t$$

$$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$$

$$\mathbf{F}_s = -kx$$

$$U_s = \frac{1}{2}kx^2$$

$$T = \frac{2\pi}{\omega} = \frac{1}{f}$$

$$T_s = 2\pi\sqrt{\frac{m}{k}}$$

$$T_p = 2\pi\sqrt{\frac{\ell}{g}}$$

$$\mathbf{F}_G = -\frac{Gm_1m_2}{r^2} \hat{\mathbf{r}}$$

$$U_G = -\frac{Gm_1m_2}{r}$$

$a$  = acceleration  
 $F$  = force  
 $f$  = frequency  
 $h$  = height  
 $I$  = rotational inertia  
 $J$  = impulse  
 $K$  = kinetic energy  
 $k$  = spring constant  
 $\ell$  = 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  
 $\mu$  = coefficient of friction  
 $\theta$  = angle  
 $\boldsymbol{\tau}$  = torque  
 $\omega$  = angular speed  
 $\alpha$  = angular acceleration

**ELECTRICITY AND MAGNETISM**

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r^2}$$

$$\mathbf{E} = \frac{\mathbf{F}}{q}$$

$$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{Q}{\epsilon_0}$$

$$E = -\frac{dV}{dr}$$

$$V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$$

$$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r}$$

$$C = \frac{Q}{V}$$

$$C = \frac{\kappa\epsilon_0 A}{d}$$

$$C_p = \sum_i C_i$$

$$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$$

$$I = \frac{dQ}{dt}$$

$$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$$

$$R = \frac{\rho\ell}{A}$$

$$V = IR$$

$$R_s = \sum_i R_i$$

$$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$$

$$P = IV$$

$$\mathbf{F}_M = q\mathbf{v} \times \mathbf{B}$$

$$\oint \mathbf{B} \cdot d\boldsymbol{\ell} = \mu_0 I$$

$$\mathbf{F} = \int I d\boldsymbol{\ell} \times \mathbf{B}$$

$$B_s = \mu_0 nI$$

$$\phi_m = \int \mathbf{B} \cdot d\mathbf{A}$$

$$\mathcal{E} = -\frac{d\phi_m}{dt}$$

$$\mathcal{E} = -L \frac{dI}{dt}$$

$$U_L = \frac{1}{2}LI^2$$

$A$  = area  
 $B$  = magnetic field  
 $C$  = capacitance  
 $d$  = distance  
 $E$  = electric field  
 $\mathcal{E}$  = emf  
 $F$  = force  
 $I$  = current  
 $L$  = inductance  
 $\ell$  = length  
 $n$  = number of loops of wire per unit length  
 $P$  = power  
 $Q$  = charge  
 $q$  = point charge  
 $R$  = resistance  
 $r$  = distance  
 $t$  = time  
 $U$  = potential or stored energy  
 $V$  = electric potential  
 $v$  = velocity or speed  
 $\rho$  = resistivity  
 $\phi_m$  = magnetic flux  
 $\kappa$  = dielectric constant

## 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
$C = 2\pi r$	$\ell$ = length
Parallelepiped	w = width
$V = \ell wh$	r = radius

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

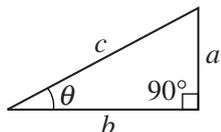
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

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<sup>®</sup> PHYSICS C: ELECTRICITY AND MAGNETISM  
FREE-RESPONSE QUESTIONS**

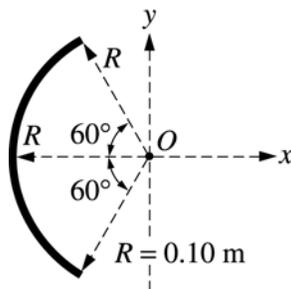
**PHYSICS C**

**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.

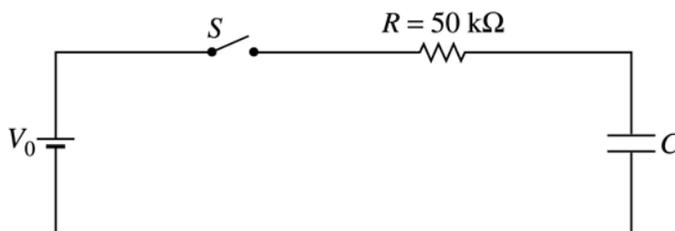
A rod of uniform linear charge density  $\lambda = +1.5 \times 10^{-5}$  C/m is bent into an arc of radius  $R = 0.10$  m. The arc is placed with its center at the origin of the axes shown above.

- (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.

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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.

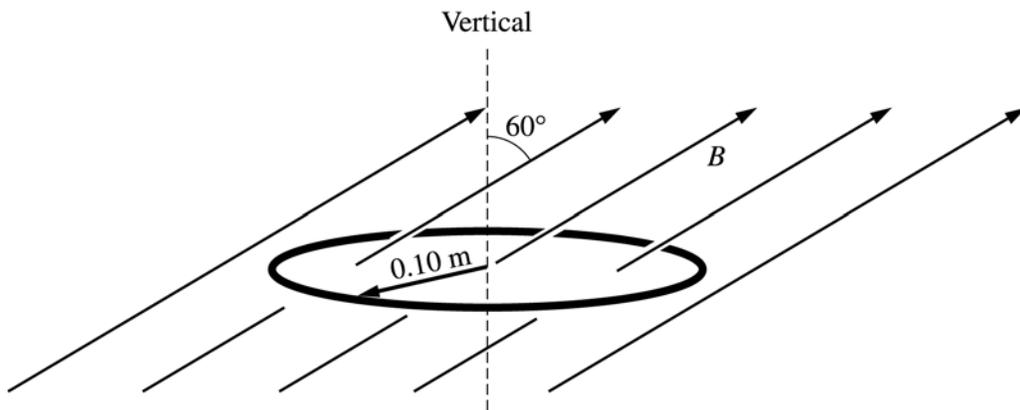
- Determine the value of the charging voltage  $V_0$  predicted by the equation.
- Determine the value of the capacitance  $C$  predicted by the equation.
- The charging voltage is measured in the laboratory and found to be greater than predicted in part (a).
  - Give one possible explanation for this finding.
  - Explain the implications that your answer to part i has for the predicted value of the capacitance.
- 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.
  - Indicate how a resistor may be added to decrease the charging time. Add the necessary resistor and connections to the following diagram.



- 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.



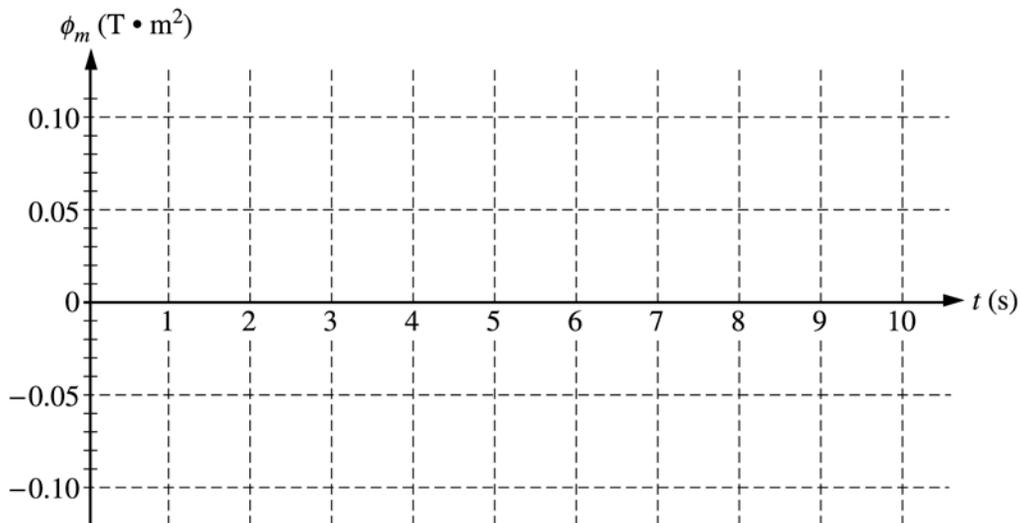
**2002 AP<sup>®</sup> PHYSICS C: ELECTRICITY AND MAGNETISM  
FREE-RESPONSE QUESTIONS**



E&M 3.

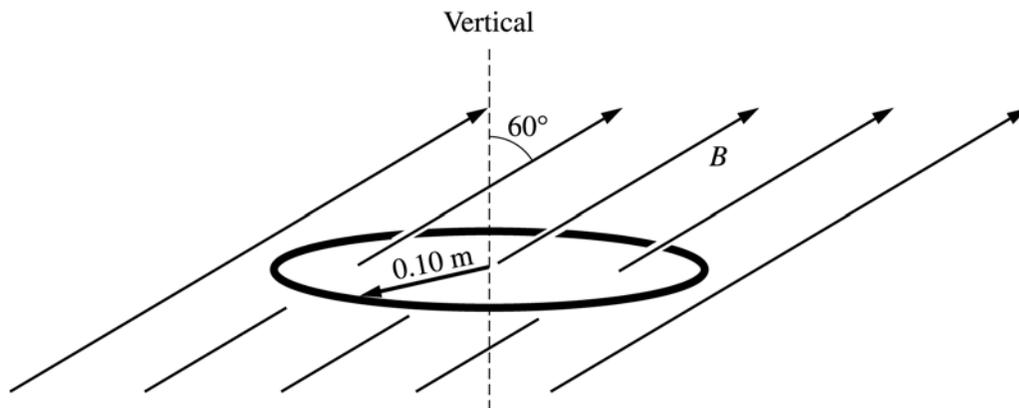
A circular wire loop with radius 0.10 m and resistance  $50 \Omega$  is suspended horizontally in a magnetic field of magnitude  $B$  directed upward at an angle of  $60^\circ$  with the vertical, as shown above. The magnitude of the field in teslas is given as a function of time  $t$  in seconds by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

- Determine the magnetic flux  $\phi_m$  through the loop as a function of time.
- Graph the magnetic flux  $\phi_m$  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**