



AP[®] Physics C: Electricity & Magnetism 2003 Free-Response Questions

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TABLE OF INFORMATION FOR 2003

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

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.
- IV. For mechanics and thermodynamics equations, W represents the work done on a system.

ADVANCED PLACEMENT PHYSICS C EQUATIONS FOR 2003

MECHANICS

$$v = v_0 + at$$

$$x = x_0 + v_0 t + \frac{1}{2} at^2$$

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

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

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

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

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

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

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

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

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

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

$$\Delta U_g = mgh$$

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

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

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

$$L = \int r^2 dm = \Sigma mr^2$$

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

$$v = r\omega$$

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

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

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

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

$$\mathbf{F}_s = -k\mathbf{x}$$

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

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

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

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

$$\mathbf{F}_G = -\frac{Gm_1 m_2}{r^2} \hat{\mathbf{r}}$$

$$U_G = -\frac{Gm_1 m_2}{r}$$

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

ELECTRICITY AND MAGNETISM

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

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

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

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

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

$$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$

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

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

$$C_p = \sum_i C_i$$

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

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

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

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

$$V = IR$$

$$R_s = \sum_i R_i$$

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

$$P = IV$$

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

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

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

$$B_s = \mu_0 nI$$

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

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

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

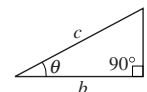
$$U_L = \frac{1}{2} LI^2$$

A = area
 B = magnetic field
 C = capacitance
 d = distance
 E = electric field
 $\mathcal{E}$ = emf
 F = force
 I = current
 L = inductance
 ℓ = 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
 ρ = resistivity
 ϕ_m = magnetic flux
 κ = dielectric constant

ADVANCED PLACEMENT PHYSICS C EQUATIONS FOR 2003

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
 $a^2 + b^2 = c^2$
 $\sin \theta = \frac{a}{c}$
 $\cos \theta = \frac{b}{c}$
 $\tan \theta = \frac{a}{b}$



CALCULUS

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

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

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

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

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

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

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

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

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

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

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

2003 AP[®] PHYSICS C: ELECTRICITY AND MAGNETISM
FREE-RESPONSE QUESTIONS

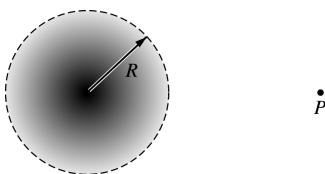
PHYSICS C

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 spherical cloud of charge of radius R contains a total charge $+Q$ with a nonuniform volume charge density that varies according to the equation

$$\rho(r) = \rho_0 \left(1 - \frac{r}{R} \right) \text{ for } r \leq R \text{ and} \\ \rho = 0 \text{ for } r > R,$$

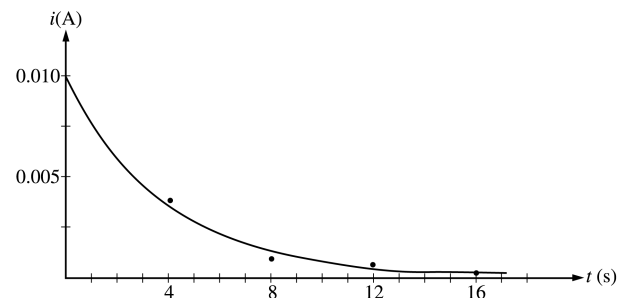
where r is the distance from the center of the cloud. Express all algebraic answers in terms of Q , R , and fundamental constants.

- Determine the following as a function of r for $r > R$.
 - The magnitude E of the electric field
 - The electric potential V
- A proton is placed at point P shown above and released. Describe its motion for a long time after its release.
- An electron of charge magnitude e is now placed at point P , which is a distance r from the center of the sphere, and released. Determine the kinetic energy of the electron as a function of r as it strikes the cloud.
- Derive an expression for ρ_0 .
- Determine the magnitude E of the electric field as a function of r for $r \leq R$.

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FREE-RESPONSE QUESTIONS

E&M. 2.

In the laboratory, you connect a resistor and a capacitor with unknown values in series with a battery of emf $\mathcal{E} = 12 \text{ V}$. You include a switch in the circuit. When the switch is closed at time $t = 0$, the circuit is completed, and you measure the current through the resistor as a function of time as plotted below.

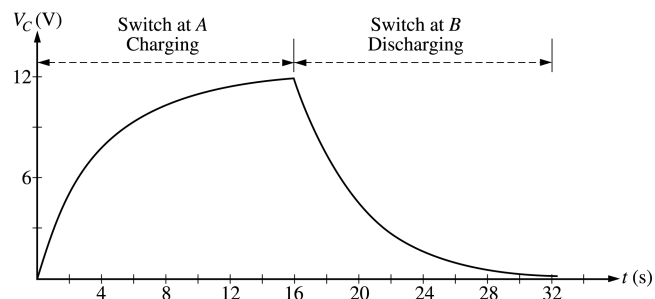


A data-fitting program finds that the current decays according to the equation $i(t) = \frac{\mathcal{E}}{R} e^{-t/4}$.

- Using common symbols for the battery, the resistor, the capacitor, and the switch, draw the circuit that you constructed. Show the circuit before the switch is closed and include whatever other devices you need to measure the current through the resistor to obtain the above plot. Label each component in your diagram.
- Having obtained the curve shown above, determine the value of the resistor that you placed in this circuit.
- What capacitance did you insert in the circuit to give the result above?

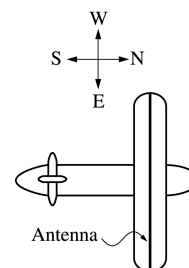
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FREE-RESPONSE QUESTIONS

You are now asked to reconnect the circuit with a new switch in such a way as to charge and discharge the capacitor. When the switch in the circuit is in position *A*, the capacitor is charging; and when the switch is in position *B*, the capacitor is discharging, as represented by the graph below of voltage V_C across the capacitor as a function of time.

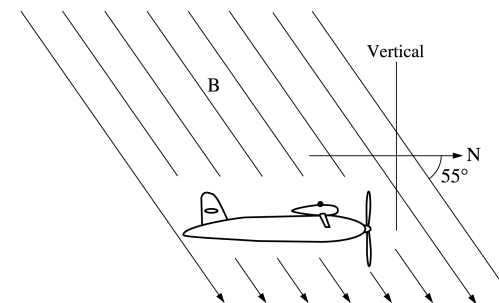


- (d) Draw a schematic diagram of the RC circuit that you constructed that would produce the graph above. Clearly indicate switch positions *A* and *B* on your circuit diagram and include whatever other devices you need to measure the voltage across the capacitor to obtain the above plot. Label each component in your diagram.

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FREE-RESPONSE QUESTIONS



Top View

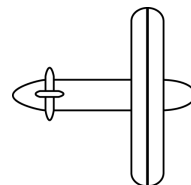


Side View

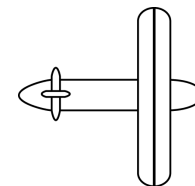
E&M. 3.

An airplane has an aluminum antenna attached to its wing that extends 15 m from wingtip to wingtip. The plane is traveling north at 75 m/s in a region where Earth's magnetic field has both a vertical component and a northward component, as shown above. The net magnetic field is at an angle of 55 degrees from horizontal and has a magnitude of 6.0×10^{-5} T.

- (a) On the figure below, indicate the direction of the magnetic force on electrons in the antenna. Justify your answer.

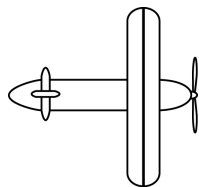


- (b) Determine the magnitude of the electric field generated in the antenna.
 (c) Determine the potential difference between the ends of the antenna.
 (d) On the figure below, indicate which end of the antenna is at higher potential.



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FREE-RESPONSE QUESTIONS**

- (e) The ends of the antenna are now connected by a conducting wire so that a closed circuit is formed.
- Describe the condition(s) that would be necessary for a current to be induced in the circuit. Give a specific example of how the condition(s) could be created.
 - For the example you gave in i. above, indicate the direction of the current in the antenna on the figure below.



END OF SECTION II, ELECTRICITY AND MAGNETISM