2021

AP Physics C: Electricity and Magnetism Answers

Que-1 →

$$V = IR$$
$$Q = CV$$
$$Q = Q_0 e^{-t/\tau}$$
$$\tau = RC$$

Que-2 →

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

Que-3 →

$$e = -\frac{d\phi}{dt}, \quad \phi = \vec{B}\cdot\vec{A}$$

$$e = e_0 \sin\omega t \qquad P = \frac{e^2}{R}$$
$$e_0 = NBA\omega \qquad \omega = 2\pi/T$$

ADVANCED PLACEMENT PHYSICS C TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS

Proton mass, $m_p = 1.67 \times 10^{-27}$ kg

Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg

Electron mass, $m_e = 9.11 \times 10^{-31}$ kg

Avogadro's number, $N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$

Universal gas constant, $R = 8.31\ \text{J/(mol}\cdot\text{K)}$

Boltzmann's constant, $k_B = 1.38 \times 10^{-23}$ J/K

Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C

1 electron volt, $1\ \text{eV} = 1.60 \times 10^{-19}$ J

Speed of light, $c = 3.00 \times 10^8$ m/s

Universal gravitational constant, $G = 6.67 \times 10^{-11}\ (\text{N}\cdot\text{m}^2)/\text{kg}^2$

Acceleration due to gravity at Earth's surface, $g = 9.8\ \text{m/s}^2$

1 unified atomic mass unit, $1\ \text{u} = 1.66 \times 10^{-27}\ \text{kg} = 931\ \text{MeV}/c^2$

Planck's constant, $h = 6.63 \times 10^{-34}\ \text{J}\cdot\text{s} = 4.14 \times 10^{-15}\ \text{eV}\cdot\text{s}$

$hc = 1.99 \times 10^{-25}\ \text{J}\cdot\text{m} = 1.24 \times 10^3\ \text{eV}\cdot\text{nm}$

Vacuum permittivity, $\varepsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/(\text{N}\cdot\text{m}^2)$

Coulomb's law constant, $k = 1/(4\pi\varepsilon_0) = 9.0 \times 10^9\ (\text{N}\cdot\text{m}^2)/\text{C}^2$

Vacuum permeability, $\mu_0 = 4\pi \times 10^{-7}\ (\text{T}\cdot\text{m})/\text{A}$

Magnetic constant, $k' = \mu_0/(4\pi) = 1 \times 10^{-7}\ (\text{T}\cdot\text{m})/\text{A}$

1 atmosphere pressure, $1\ \text{atm} = 1.0 \times 10^5\ \text{N/m}^2 = 1.0 \times 10^5$ 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 assumptions are used in this exam.

I. The frame of reference of any problem is inertial unless otherwise stated.

II. The direction of current is the direction in which positive charges would drift.

III. The electric potential is zero at an infinite distance from an isolated point charge.

IV. All batteries and meters are ideal unless otherwise stated.

V. Edge effects for the electric field of a parallel plate capacitor are negligible unless otherwise stated.

ADVANCED PLACEMENT PHYSICS C EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

$x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2$

$v_x^2 = v_{x0}^2 + 2a_x (x - x_0)$

$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$

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

$\vec{J} = \int \vec{F}\, dt = \Delta\vec{p}$

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

$|\vec{F}_f| \le \mu |\vec{F}_N|$

$\Delta E = W = \int \vec{F} \cdot d\vec{r}$

$K = \frac{1}{2} m v^2$

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

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

$\Delta U_g = mg\Delta h$

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

$\vec{\tau} = \vec{r} \times \vec{F}$

$\vec{\alpha} = \frac{\sum \vec{\tau}}{I} = \frac{\vec{\tau}_{net}}{I}$

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

$x_{cm} = \frac{\sum m_i x_i}{\sum m_i}$

$v = r\omega$

$\vec{L} = \vec{r} \times \vec{p} = I\vec{\omega}$

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

$\omega = \omega_0 + \alpha t$

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

a = acceleration
E = energy
F = force
f = frequency
h = height
I = rotational inertia
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
L = angular momentum
m = mass
P = power
p = momentum
r = radius or distance
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
ϕ = phase angle

$\vec{F}_s = -k\Delta\vec{x}$

$U_s = \frac{1}{2} k (\Delta x)^2$

$x = x_{\max}\cos(\omega t + \phi)$

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

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

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

$|\vec{F}_G| = \frac{G m_1 m_2}{r^2}$

$U_G = -\frac{G m_1 m_2}{r}$

ELECTRICITY AND MAGNETISM

$|\vec{F}_E| = \frac{1}{4\pi\varepsilon_0}\left|\frac{q_1 q_2}{r^2}\right|$

$\vec{E} = \frac{\vec{F}_E}{q}$

$\oint \vec{E} \cdot d\vec{A} = \frac{Q}{\varepsilon_0}$

$E_x = -\frac{dV}{dx}$

$\Delta V = -\int \vec{E} \cdot d\vec{r}$

$V = \frac{1}{4\pi\varepsilon_0}\sum_i \frac{q_i}{r_i}$

$U_E = qV = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}$

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

$C = \frac{\kappa \varepsilon_0 A}{d}$

$C_p = \sum_i C_i$

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

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

$U_C = \frac{1}{2} Q\Delta V = \frac{1}{2} C (\Delta V)^2$

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

$\vec{E} = \rho \vec{J}$

$I = N e v_d A$

$I = \frac{\Delta V}{R}$

$R_s = \sum_i R_i$

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

$P = I\Delta V$

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 = radius or distance
t = time
U = potential or stored energy
V = electric potential
v = velocity or speed
ρ = resistivity
Φ = flux
κ = dielectric constant

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

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

$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I\, d\vec{\ell} \times \hat{r}}{r^2}$

$\vec{F} = \int I\, d\vec{\ell} \times \vec{B}$

$B_s = \mu_0 n I$

$\Phi_B = \int \vec{B} \cdot d\vec{A}$

$\mathcal{E} = \oint \vec{E} \cdot d\vec{\ell} = -\frac{d\Phi_B}{dt}$

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

$U_L = \frac{1}{2} L I^2$

ADVANCED PLACEMENT PHYSICS C EQUATIONS

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

Triangle
$A = \frac{1}{2}bh$

Circle
$A = \pi r^2$
$C = 2\pi r$
$s = r\theta$

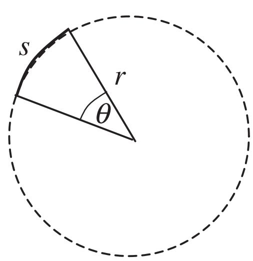
Rectangular Solid
$V = \ell wh$

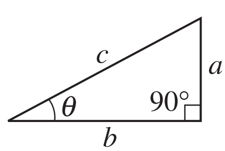
Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$

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
s = arc length
θ = angle





CALCULUS!

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

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

$$\frac{d}{dx}\left(e^{ax}\right) = ae^{ax}$$

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

$$\frac{d}{dx}[\sin(ax)] = a\cos(ax)$$

$$\frac{d}{dx}[\cos(ax)] = -a\sin(ax)$$

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

$$\int e^{ax}\,dx = \frac{1}{a}e^{ax}$$

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

$$\int \cos(ax)\,dx = \frac{1}{a}\sin(ax)$$

$$\int \sin(ax)\,dx = -\frac{1}{a}\cos(ax)$$

VECTOR PRODUCTS!

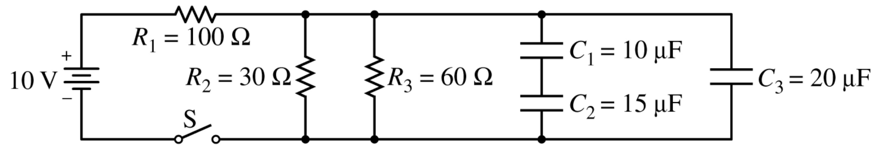
$\vec{A}\bullet\vec{B} = AB\cos\theta$

$\left|\vec{A}\times\vec{B}\right| = AB\sin\theta$

Begin your response to QUESTION 1 on this page. PHYSICS C: ELECTRICITY AND MAGNETISM

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 this booklet in the spaces provided after each part.



1. The circuit shown above is composed of an ideal 10 V battery, three resistors and three capacitors with the values shown, and an open switch S. The capacitors are initially uncharged. Switch S is now closed.

(a) Calculate the current through R_1 immediately after switch S is closed.

when switch S is closed, all capacitor will act as a short circuit

$$I = \frac{10}{100} = 0.1\ A$$

Switch S has been closed for a long time, and the circuit has reached a steady state.

(b) Calculate the potential difference across R_1.

$$V_{R_1} = \left(\frac{10}{100 + \frac{30 \times 60}{30+60}}\right) \times 100 = \left(\frac{10 \times 100}{100 + 20}\right) = 8.3\ \text{Volt}$$

(c)

i. Calculate the charge stored on the positive plate of capacitor C_2.

Now potential difference across capacitor C_1 & $C_2 = 10 - 8.3 = 1.7$ Volt

$$Q = \left(\frac{C_1 C_2}{C_1 + C_2}\right)(1.7) = \frac{10 \times 15}{25} \times 1.7 = 6 \times 1.7 = 10.2\ \mu C$$

ii. Is the charge stored on capacitor C_3 greater than, less than, or equal to the charge stored on capacitor C_2?

✓ ____ Greater than _____ Less than _____ Equal to

Justify your answer.

charge in capacitor C_3, $Q = C_3 \times 1.7 = 20 \times 10^{-6} \times 1.7 = 34\ \mu C$

Continue your response to QUESTION 1 on this page.

Switch S is then opened.

(d)

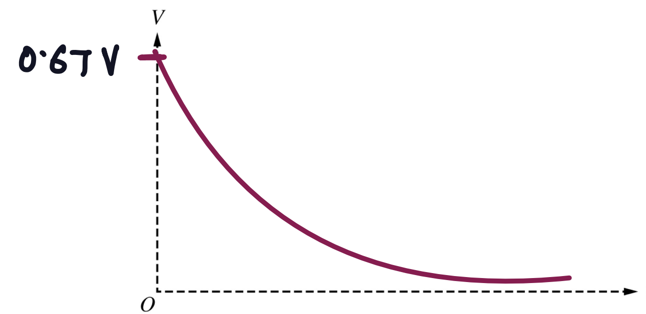
i. Determine the current through R_1 immediately after the switch is opened.

$I_{(across\ R_1)} = 0$

ii. Calculate the current through R_2 immediately after the switch is opened.

$V_{R_2} = 1{\cdot}70$ Volt then $I_{R_2} = \frac{V_{R_2}}{R_2} = \frac{1{\cdot}70}{30} = {\cdot}0566$ Amp

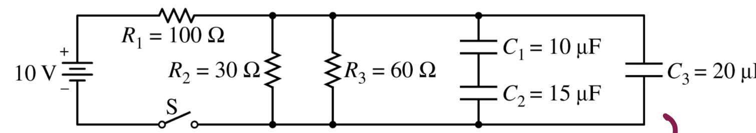
(e) On the axes below, sketch a graph of the potential difference V across capacitor C_2 as a function of time t if switch S is opened at time t = 0. Label the maximum value.



Capacitor C_3 is replaced by two 10 μF capacitors connected in series, switch S is closed, and the circuit reaches equilibrium. Switch S is then opened at time t = 0.

(f) For t > 0, would the sketch of a graph of the new voltage across C_2 as a function of time be above, below, or the same as the sketch for part (e) ?

_____ Above _____ Below ✓ _____ The same Justify your answer.



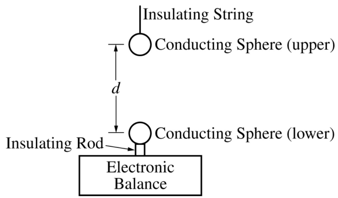
Replaced by two 10μF capacitor in series then C_3 will be 5μF instead of 20μF

Hence Total capacitance decreases then

$\tau = RC$ will also decrease.

then new curve will be below the previous curve.

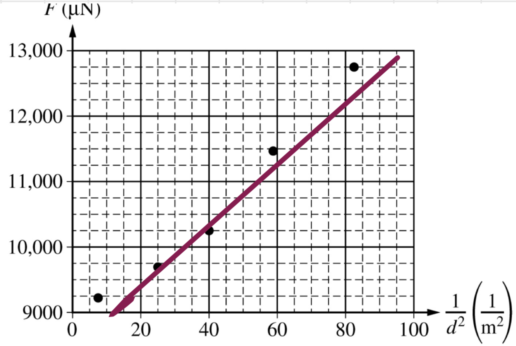
Begin your response to QUESTION 2 on this page.



2. Students perform an experiment to study the force between two charged objects using the apparatus shown above, which contains two identical conducting spheres. The upper sphere is attached to an insulating string, which can be used to move the sphere downward. The lower sphere sits on an insulating rod, which is on an electronic balance. The electronic balance is zeroed before the lower sphere and insulating rod are in place.

For the first trial, a charge of Q is placed on each sphere and then the upper sphere is slowly moved downward. The students measure the distance d between the centers of the spheres and the magnitude F of the force that appears on the electronic balance. The recorded data are shown on the graph of F as a function of $1/d^2$ shown below.

i. Draw a line that represents the best fit to the points shown.

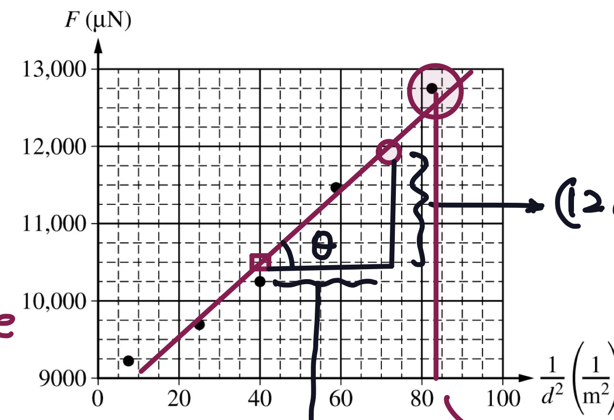


ii. Use the graph to calculate the charge Q.

$$F = \frac{1}{4\pi\epsilon_0}\frac{Q.Q}{d^2}$$

$$F = \left(\frac{1}{4\pi\epsilon_0}\right) Q^2 \left(\frac{1}{d^2}\right)$$

$$\frac{F}{\left(\frac{1}{d^2}\right)} = \frac{Q^2}{4\pi\epsilon_0} = \text{slope of the graph}$$



$$\frac{(12000 - 10500)\times10^{-6}\,N}{(72-40)\,m^{-2}} = 9\times10^{9}\times Q^2$$

$$Q = \sqrt{\frac{1500\times10^{-6}}{32\times9\times10^{9}}} = 7.2\times10^{-8}\,C$$

iii. On the graph on the previous page, draw a circle around the data point that was taken when the distance between the centers of the spheres was the least.

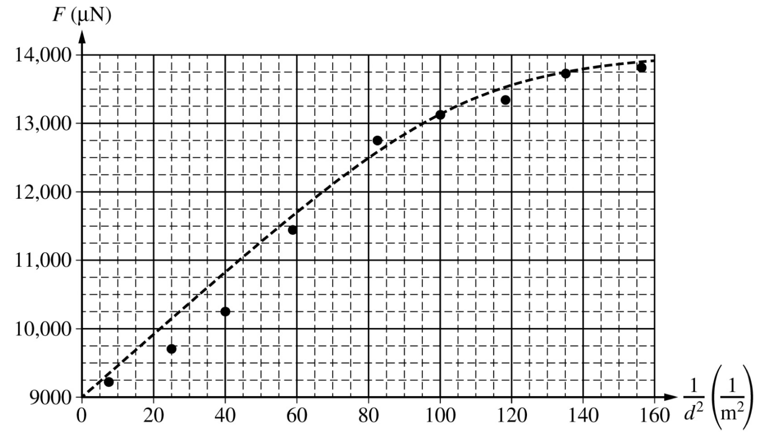
(shown on previous page)

iv. Determine the distance between the centers of the spheres for the data point indicated above.

$$\frac{1}{d^2} = 82.5\ m^{-2} \Rightarrow d = 0.11\ m$$

v. What physical quantity does the vertical intercept represent? Justify your answer.

The vertical intercept represents the force when the top sphere is infinitely away, so the only force acting on the scale is the weight of the lower sphere and insulating rod.



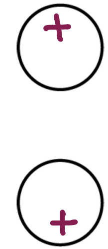
The experiment is extended by collecting additional data points, which appear on the right side of the graph shown above. The new data points do not follow the linear pattern seen with the first points. The group of students tries to explain this discrepancy.

(b) One student suspects that charge is slowly leaking off the top sphere. Could this explain the discrepancy?
__✓__ Yes _____ No
Justify your answer.

Later the force measured is lesser than actual value then decrease in charge only explain the theory.

Continue your response to QUESTION 2 on this page.

i. On the circles representing the spheres below, use a single "+" sign on each sphere to represent the locations of highest concentration of the excess positive charges.

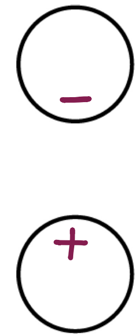


ii. Explain how this rearrangement could be responsible for the discrepancy.

on a conductor excess charge is free to move any where due to repulsion thus the repelling force decreases.

(d) A third student suggests that the experiment be modified so that the top sphere is given a negative charge that is equal in magnitude to the positive charge given to the bottom sphere.

i. On the circles representing the spheres below, use a single "+" sign on the bottom sphere to represent the location of highest concentration of the excess positive charges. Use a single "–" sign on the top sphere to represent the location of the highest concentration of the excess negative charges.



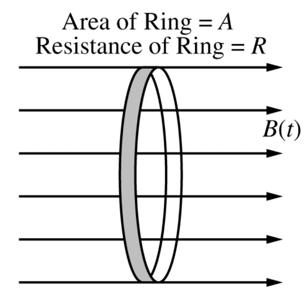
ii. For a separation distance equal to that of the data point indicated in part (a) (iii), would the magnitude of the force reading with spheres of opposite charges be greater than, less than, or equal to the magnitude of the force reading with spheres of the same charges?

_____ Greater than __✓__ Less than _____ Equal to Justify your answer.

opposite charge (Attraction will take place)
decrease in Normal force exerted by the scale on lower sphere, thus the reading of the scale will be less than when the sphere had the same charge

Begin your response to QUESTION 3 on this page.

3. A thin, conducting ring of area A and resistance R is aligned in a uniform magnetic field directed to the right and perpendicular to the plane of the ring, as shown. At time t = 0, the magnitude of the magnetic field is B_0.



At t = 1 s, the magnitude of the magnetic field begins to decrease according to the equation, $B(t) = \frac{\beta}{t}$ where b has units of T·s

(a) Derive an equation for the magnitude of the induced current I in the ring as a function of t for t > 1 s. Express your answer in terms of b, A, R, t, and physical constants, as appropriate.

$$e = \left|\frac{d\phi}{dt}\right| = \left|\frac{d}{dt}(B.A)\right| = \left|A\frac{d}{dt}\left(\beta/t\right)\right|$$

$$= \left|A\beta\left(-\frac{1}{t^2}\right)\right| = \left|\frac{A\beta}{t^2}\right|$$

$$|I| = \left|\frac{\Delta V}{R}\right| = \left|\frac{A\beta}{Rt^2}\right|$$

Assume A = 0.50 m^2, R = 2.0 Ω, and β = 0.50 Ts .

(b) Calculate the electrical energy dissipated in the ring from t = 1 s to t = 2 s.

$$E = \int P.dt = \int I^2 R\,dt = \int_1^2 \left(\frac{AB}{Rt^2}\right)^2 R\,dt$$

$$= \int_1^2 \frac{A^2B^2}{R^2t^4} R.dt = \frac{A^2B^2}{R}\int_1^2 t^{-4}dt$$

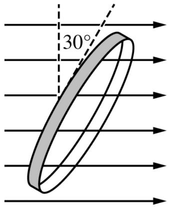
$$= \frac{A^2B^2}{R}\left[\frac{t^{-4+1}}{-4+1}\right]_1^2 = \frac{A^2B^2}{R}\left[-\frac{t^{-3}}{3}\right]_1^2$$

$$= \frac{A^2B^2}{3R}\left[-\frac{1}{t^3}\right]_1^2 = \frac{A^2B^2}{3R}\left[-\frac{1}{8}+\frac{1}{1}\right]$$

$$= -\frac{A^2B^2}{3R}\left[\frac{1-8}{8}\right] = +\frac{7A^2B^2}{24R} = \frac{7(0.50)^2(0.50)^4}{24 \times 2.0}$$

$$= .0091\,J$$

Continue your response to QUESTION 3 on this page.



The ring is then rotated so that the plane of the ring is aligned at a 30° angle to the magnetic field, as shown.

The magnitude of the magnetic field is reset to a magnitude of B0 at a new time t = 0 and again begins to

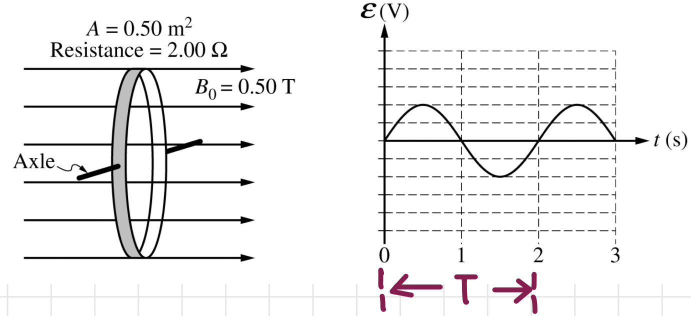
decrease at t = 1 s according to the equation , where b has units of T.s

(c) Will the amount of energy dissipated in the ring from t = 1 s to t = 2 s be greater than, less than, or equal to the energy dissipated in part (b) ?

_____ Greater than __✓__ Less than _____ Equal to Justify your answer.

As the ring rotates, fewer magnetic field lines will pass through the ring, ϕ is less than before, $\frac{d\phi}{dt}$ is less

e is Less then $P = \frac{e^2}{R}$ is less.



The ring is now mounted on an axle that is perpendicular to the magnetic field. The magnitude of the magnetic field is now held at a constant B_0 = 0.50 T, as shown. The ring rotates about the axle, and the emf e induced in the ring as a function of time t is shown on the graph.

(d) Calculate the angular speed w of the rotating ring in rad/s.

T = 2 sec (from the graph)

$$w = \frac{2\pi}{T} = \frac{2\pi}{2} = \pi \text{ rad/sec}$$

$$= 3.14 \text{ radian/sec}$$

(e) Calculate the magnitude of the maximum emf e_{MAX} induced in the ring.

$$e = -\frac{d\phi}{dt} = -\frac{d}{dt}\bar{B}\cdot\bar{A} = -\frac{d}{dt} BA\cos\omega t$$

$$= -BA\left(\frac{d}{dt}\cos\omega t\right)$$

$$= -BA(-\omega\sin\omega t) = BA\omega\sin\omega t$$

compare with $e = e_0 \sin\omega t$

$$e_0 = e_{max} = BA\omega$$

$$= (0.50)(0.50)\left(3.14\,\frac{rad}{sec}\right)$$

$$= 0.79 \text{ volt}$$

The ring now begins to rotate at an angular speed 2w.

(f) On the graph below, draw a curve to indicate the new induced emf e in the ring. The dashed curve shows the emf induced under the original conditions.

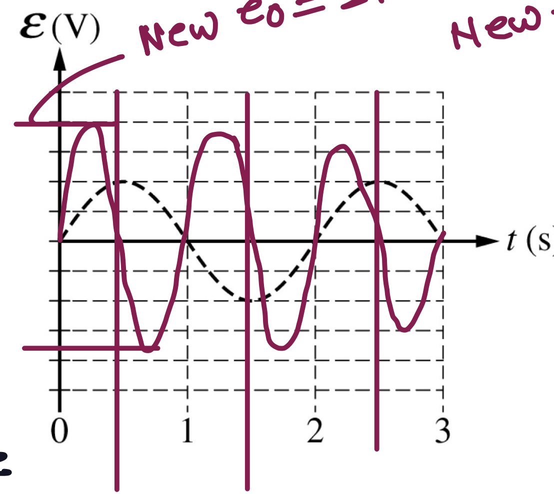
$w = \frac{2\pi}{T}$ → original condition

New condition

$2w = \frac{2\pi}{T'} \Rightarrow T' = \frac{2\pi}{2w} = \frac{1}{2}\left(\frac{2\pi}{w}\right)$

$= T/2$

New time period will be half the original time period



But, $e_0 = NBAw$ become $2NBAw$ double

Justify your sketch, specifically identifying and addressing any similarities or differences between the sketch and the original graph.

STOP

END OF EXAM

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