The College Board
Advanced Placement Examination
PHYSICS C
SECTION II

TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\text{u} = 1.66 \times 10^{-27}$ kg
	$= 931$ MeV$/c^2$
Rest mass of the proton,	$m_p = 1.67 \times 10^{-27}$ kg
Rest mass of the neutron,	$m_n = 1.67 \times 10^{-27}$ kg
Rest mass of the electron,	$m_e = 9.11 \times 10^{-31}$ kg
Magnitude of the electron charge,	$e = 1.60 \times 10^{-19}$ C
Avogadro's number,	$N_0 = 6.02 \times 10^{23}$ mol^{-1}
Universal gas constant,	$R = 8.31$ J/(mol · K)
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K
Speed of light,	$c = 3.00 \times 10^8$ m/s
Planck's constant,	$h = 6.63 \times 10^{-34}$ J · s
	$= 4.14 \times 10^{-15}$ eV · s
	$hc = 1.99 \times 10^{-25}$ J · m
	$= 1.24 \times 10^3$ eV · nm
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}$ C^2/N · m^2
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9$ N · m^2/C^2
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ Wb/(A · m)
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}$ Wb/(A · m)
Universal gravitational constant,	$G = 6.67 \times 10^{-11}$ m^3/kg · s^2
Acceleration due to gravity at the Earth's surface,	$g = 9.8$ m/s^2
1 atmosphere pressure,	1 atm $= 1.0 \times 10^5$ N/m^2
	$= 1.0 \times 10^5$ Pa
1 electron volt,	1 eV $= 1.60 \times 10^{-19}$ J
1 angstrom,	1Å $= 1 \times 10^{-10}$ m

UNITS

Name	Symbol
meter	m
kilogram	kg
second	s
ampere	A
kelvin	K
mole	mol
hertz	Hz
newton	N
pascal	Pa
joule	J
watt	W
coulomb	C
volt	V
ohm	Ω
henry	H
farad	F
weber	Wb
tesla	T
degree Celsius	°C
electron-volt	eV

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	sin θ	cos θ	tan θ
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.

This insert may be used for reference and/or scratchwork as you answer the free-response questions, but be sure to show all your work and your answers in the pink booklet. No credit will be given for work shown on this green insert.

ADVANCED PLACEMENT PHYSICS C EQUATIONS

MECHANICS

$v = v_0 + at$

$s = s_0 + v_0 t + \frac{1}{2}at^2$

$v^2 = v_0^2 + 2a(s - s_0)$

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

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

$\mathbf{J} = \int \mathbf{F}\, dt = \triangle \mathbf{p}$

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

$F_f \leq \mu N$

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

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

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

$U_g = mgh$

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

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

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

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

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

$v = r\omega$

$\mathbf{L} = I\boldsymbol{\omega}$

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

$\omega = \omega_0 + \alpha t$

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

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

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

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

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

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

$F_G = -\frac{Gm_1m_2}{r^2}$

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

a = acceleration
F = force
f = frequency
h = height
I = rotational inertia
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
L = angular momentum
m = mass
N = normal force
P = power
p = momentum
r = distance
s = displacement
T = period
t = time
U = potential energy
v = velocity or speed
W = work
x = displacement
μ = coefficient of friction
θ = angle
τ = torque
ω = angular speed
α = angular acceleration

ELECTRICITY AND MAGNETISM

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

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

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

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

$V = \frac{1}{4\pi\epsilon_0}\sum \frac{q}{r}$

$U_E = qV$

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

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

$C_p = \sum_i C_i$

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

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

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

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

$V = IR$

$R_s = \sum_i R_i$

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

$P = IV$

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

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

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

$B_s = \mu_0 nI$

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

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

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

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

A = area
B = magnetic field strengh
C = capacitance
d = distance
E = electric field strength
$\mathcal{E}$ = 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 = magnetic flux
κ = dielectric constant

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

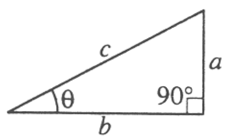
Sphere
$V = \frac{4}{3} \pi r^3$
$S = 4\pi r^2$

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

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

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

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

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

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

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

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

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

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

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

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

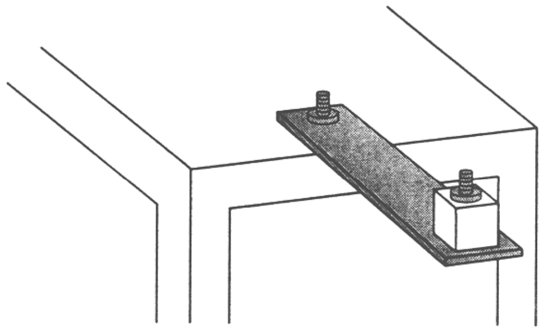
PHYSICS C

SECTION II, MECHANICS

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.



Mech. 1. A thin, flexible metal plate attached at one end to a platform, as shown above, can be used to measure mass. When the free end of the plate is pulled down and released, it vibrates in simple harmonic motion with a period that depends on the mass attached to the plate. To calibrate the force constant, objects of known mass are attached to the plate and the plate is vibrated, obtaining the data shown below.

Mass (kg)	Average Time for Ten Vibrations (s)	Period T (s)	T^2 (s^2)
0.10	8.86		
0.20	10.6		
0.30	13.5		
0.40	14.7		
0.50	17.7		

(a) Fill in the blanks in the data table.

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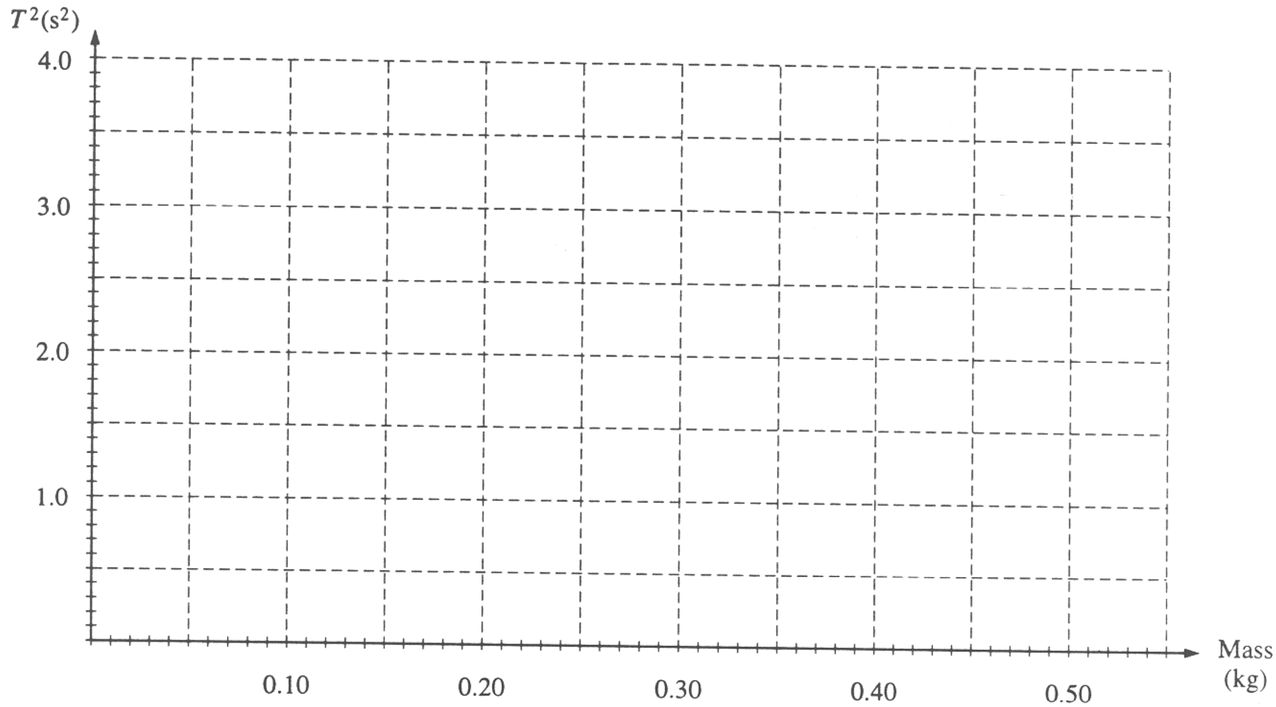
(b) On the graph below, plot T^2 *versus* mass. Draw on the graph the line that is your estimate of the best straight-line fit to the data points.



(c) An object whose mass is not known is vibrated on the plate, and the average time for ten vibrations is measured to be 16.1 s. From your graph, determine the mass of the object. Write your answer with a reasonable number of significant digits.

(d) Explain how one could determine the force constant of the metal plate.

(e) Can this device be used to measure mass aboard the space shuttle Columbia as it orbits the Earth? Explain briefly.

(f) If Columbia is orbiting at 0.3×10^6 m above the Earth's surface, what is the acceleration of Columbia due to the Earth's gravity? (Radius of Earth = 6.4×10^6 m, mass of Earth = 6.0×10^{24} kg)

(g) Since the answer to part (f) is not zero, briefly explain why objects aboard the orbiting Columbia seem weightless.

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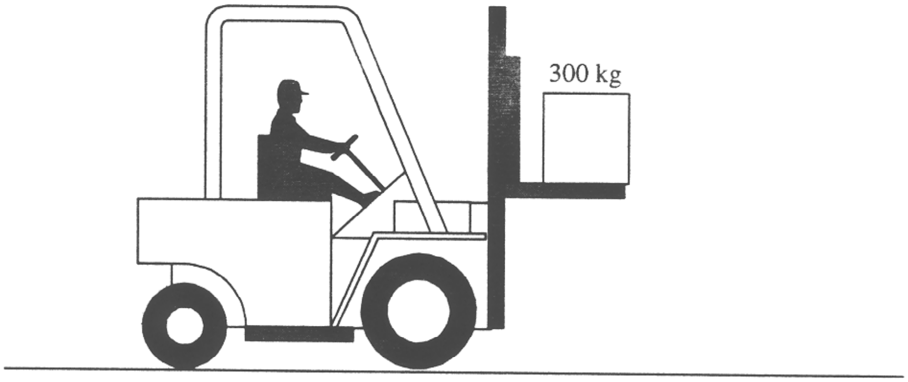


Mech. 2. A 300-kg box rests on a platform attached to a forklift, as shown above. Starting from rest at time $t = 0$, the box is lowered with a downward acceleration of $1.5\ m/s^2$.

(a) Determine the upward force exerted by the horizontal platform on the box as it is lowered.

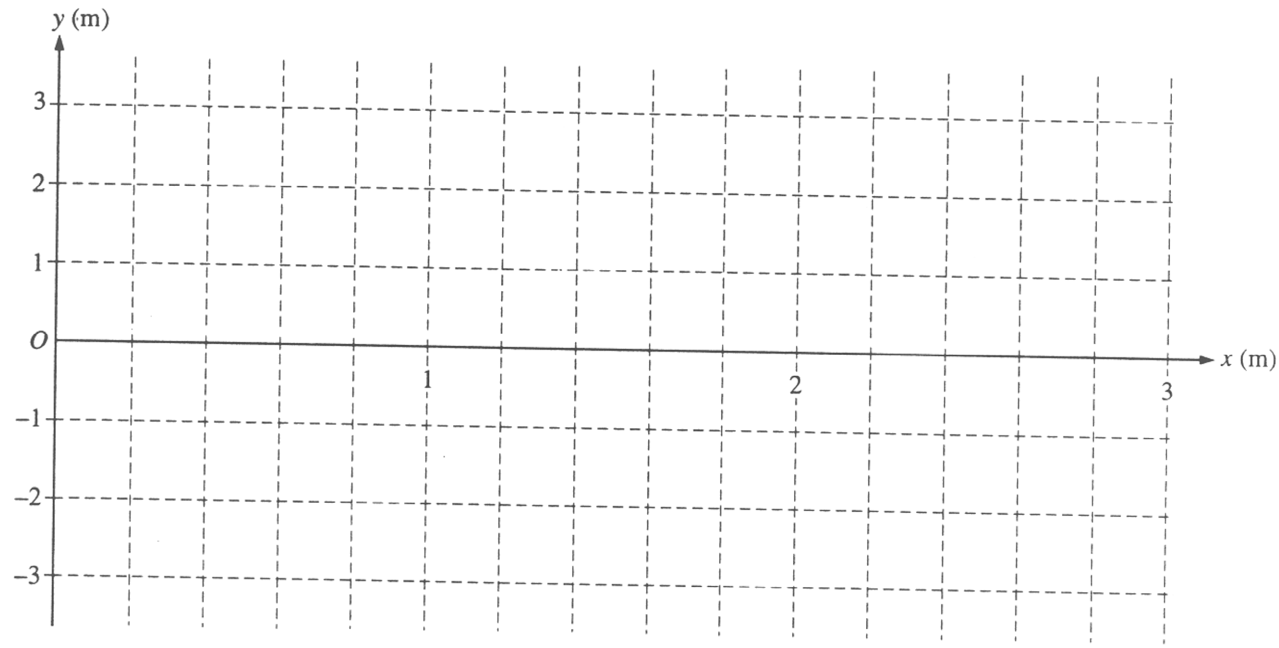
At time $t = 0$, the forklift also begins to move forward with an acceleration of $2\ m/s^2$ while lowering the box as described above. The box does not slip or tip over.

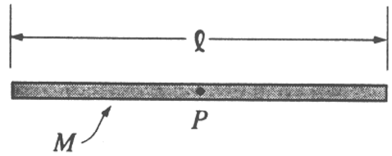
(b) Determine the frictional force on the box.

(c) Given that the box does not slip, determine the minimum possible coefficient of friction between the box and the platform.

(d) Determine an equation for the path of the box that expresses y as a function of x (and <u>not</u> of t), assuming that, at time $t = 0$, the box has a horizontal position $x = 0$ and a vertical position $y = 2$ m above the ground, with zero velocity.

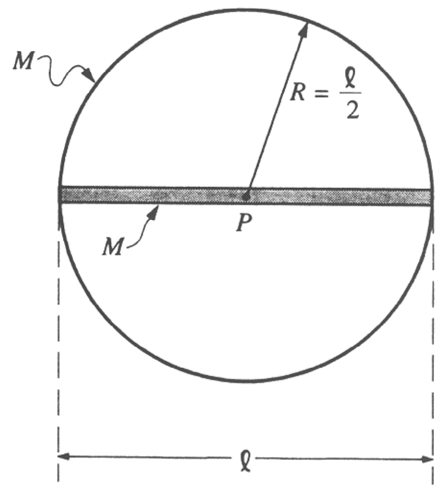
(e) On the axes below, sketch the path taken by the box.





Mech. 3. Consider a thin uniform rod of mass M and length ℓ, as shown above.

(a) Show that the rotational inertia of the rod about an axis through its center and perpendicular to its length is $M\ell^2/12$.



The rod is now glued to a thin hoop of mass M and radius $R = \ell/2$ to form a rigid assembly, as shown above. The centers of the rod and the hoop coincide at point P. The assembly is mounted on a horizontal axle through point P and perpendicular to the page.

(b) What is the rotational inertia of the rod-hoop assembly about the axle?

Several turns of string are wrapped tightly around the circumference of the hoop. The system is at rest when a cat, also of mass M, grabs the free end of the string and hangs vertically from it without swinging as it unwinds, causing the rod-hoop assembly to rotate. Neglect friction and the mass of the string.

(c) Determine the tension T in the string.

(d) Determine the angular acceleration α of the rod-hoop assembly.

(e) Determine the linear acceleration of the cat.

(f) After descending a distance $H = 5\ell/3$, the cat lets go of the string. At that instant, what is the angular momentum of the cat about point P ?

STOP

END OF SECTION II, MECHANICS

IF YOU FINISH BEFORE TIME IS CALLED, YOU MAY CHECK YOUR WORK ON SECTION II, MECHANICS, ONLY. DO NOT TURN TO ANY OTHER TEST MATERIALS.

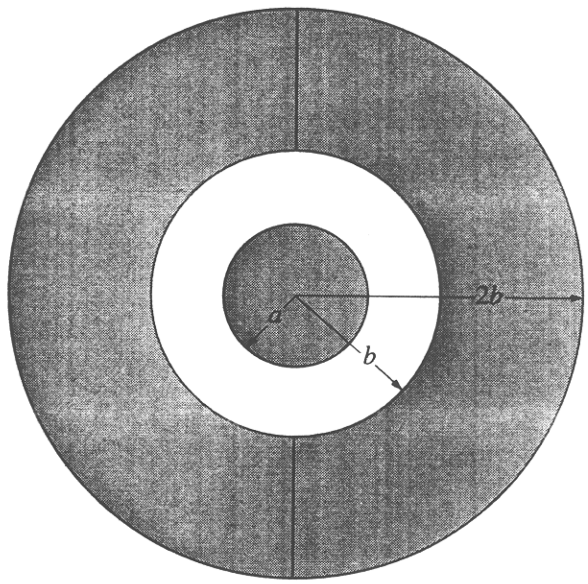
PHYSICS C

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 solid metal sphere of radius a is charged to a potential $V_0 > 0$ and then isolated from the charging source. It is then surrounded by joining two uncharged metal hemispherical shells of inner radius b and outer radius $2b$, as shown above, without touching the inner sphere or any source of charge.

(a) In terms of the given quantities and fundamental constants, determine the initial charge Q_0 on the solid sphere before it was surrounded by the outer shell.

(b) Indicate the induced charge on the following after the outer shell is in place.

i. The inner surface of the shell

ii. The outer surface of the shell

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(c) Indicate the magnitude of the electric field as a function of r and the direction (if any) of the field for the regions indicated below. Write your answers on the appropriate lines.

i. $r < a$ Magnitude ______________ Direction ______________

ii. $a < r < b$ Magnitude ______________ Direction ______________

iii. $b < r < 2b$ Magnitude ______________ Direction ______________

iv. $2b < r$ Magnitude ______________ Direction ______________

(d) Does the inner sphere exert a force on the uncharged hemispheres while the shell is being assembled? Why or why not?

(e) Although the charge on the inner solid sphere has not changed, its potential has. In terms of V_0, a, and b, determine the new potential on the inner sphere. Be sure to show your work.

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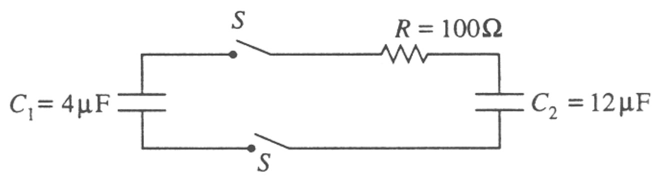

E & M 2. Capacitors 1 and 2, of capacitance $C_1 = 4\ \mu F$ and $C_2 = 12\ \mu F$, respectively, are connected in a circuit as shown above with a resistor of resistance $R = 100\ \Omega$ and two switches. Capacitor 1 is initially charged to a voltage $V_0 = 50$ V, and capacitor 2 is initially uncharged. Both of the switches S are then closed at time $t = 0$.

(a) What are the final charges on the positive plate of each of the capacitors 1 and 2 after equilibrium has been reached?

(b) Determine the difference between the initial and the final stored energy of the system after equilibrium has been reached.

(c) Write, but do not solve, an equation that, at any time after the switches are closed, relates the charge on capacitor C_1, its time derivative (which is the instantaneous current in the circuit), and the parameters V_0, R, C_1, and C_2.

The current in the resistor is given as a function of time by $I = I_0 e^{-t/\tau}$, where $I_0 = 0.5\text{A}$ and $\tau = 3 \times 10^{-4}$ s.

(d) Determine the rate of energy dissipation in the resistor as an explicit function of time.

(e) How much energy is dissipated in the resistor from the instant the switch is closed to when equilibrium is reached?

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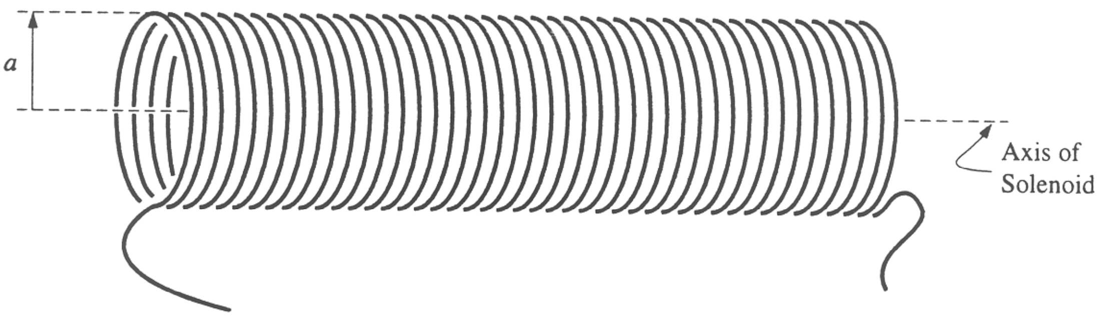
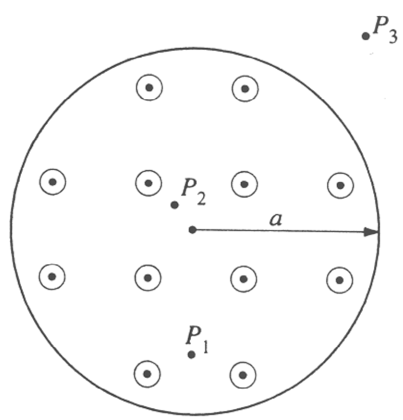


E & M 3. According to Faraday's law, the induced emf $\mathcal{E}$ due to a changing magnetic flux ϕ_m is given by $\mathcal{E} = \oint \mathbf{E} \cdot \mathbf{d\ell} = -\frac{d\phi_m}{dt}$, where $\mathbf{E}$ is the (induced) electric field and $\mathbf{d\ell}$ is a line element along the closed path of integration. A long, ideal solenoid of radius a is shown above. The magnitude of the spatially uniform magnetic field inside this solenoid (due to the current in the solenoid) is increasing at a steady rate dB/dt. Assume that the magnetic field outside the solenoid is zero.

(a) For $r < a$, where r is the distance from the axis of the solenoid, find an expression for the magnitude E of the induced electric field in terms of r and dB/dt.

(b) The figure below shows a cross section of the solenoid, with the magnetic field pointing out of the page. The electric field induced by the increasing magnetic field lies in the plane of the page. On the figure, indicate the direction of the induced electric field at the three labeled points, P_1, P_2, and P_3.



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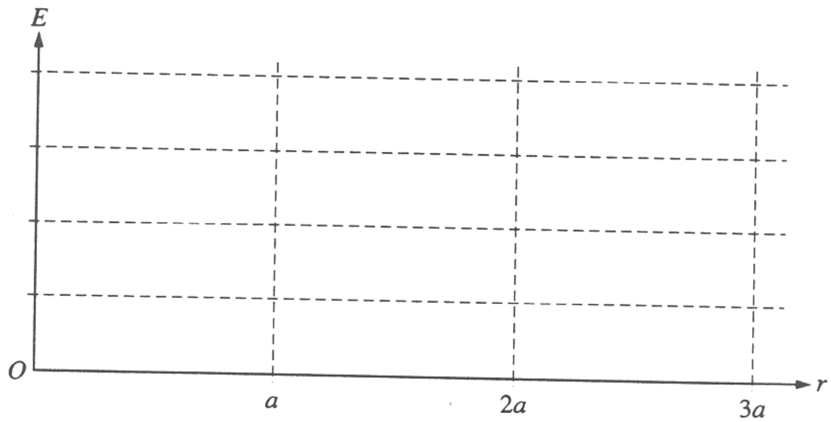
(c) For $r > a$, derive an expression for the magnitude E of the induced electric field in terms of r, a, and dB/dt.

(d) On the axes below, sketch a graph of E *versus* r for $0 \leq r \leq 3a$.



STOP

END OF SECTION II, ELECTRICITY AND MAGNETISM

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