The College Board
Advanced Placement Examination
PHYSICS C
SECTION II

TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\,u = 1.66 \times 10^{-27}$ kg
	$= 931$ MeV$/c^2$
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
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,	1 Å $= 1 \times 10^{-10}$ 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 FOR 1997

MECHANICS

$v = v_0 + at$

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

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

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

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

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

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

$F_f \leq \mu N$

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

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

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

$\triangle U_g = mgh$

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

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

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

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

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

$v = r\omega$

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

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

$\omega = \omega_0 + \alpha t$

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

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

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

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

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

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

$F_G = -\frac{G m_1 m_2}{r^2}$

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

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 = 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

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

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

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

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

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

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

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

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

$C_p = \sum_i C_i$

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

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

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

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

$V = IR$

$R_s = \sum_i R_i$

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

$P = IV$

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

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

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

$B_s = \mu_0 n I$

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

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

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

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

A = area
B = magnetic field strength
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
$A = \pi r^2$
$C = 2\pi r$

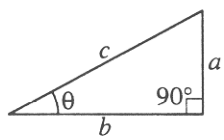
Parallelepiped
$V = \ell wh$

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

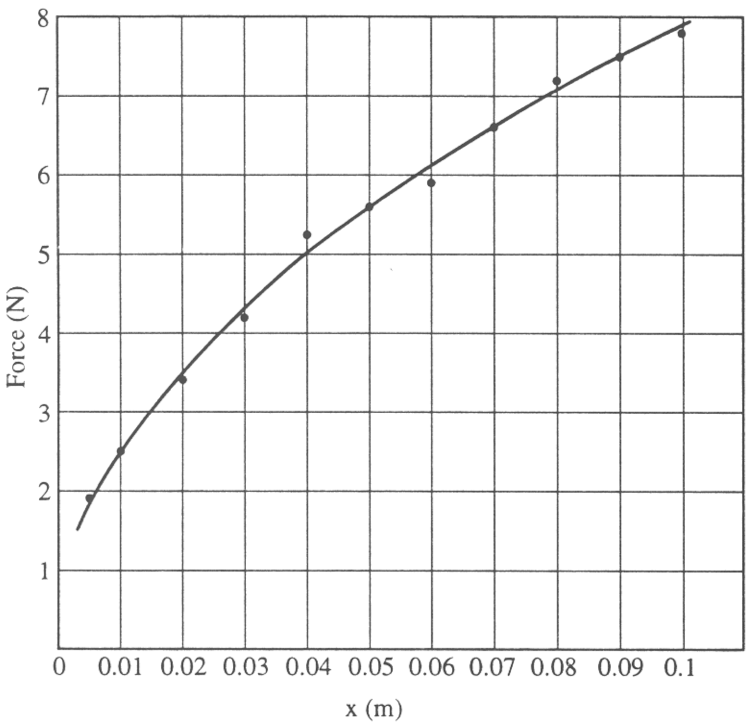
SECTION II, MECHANICS

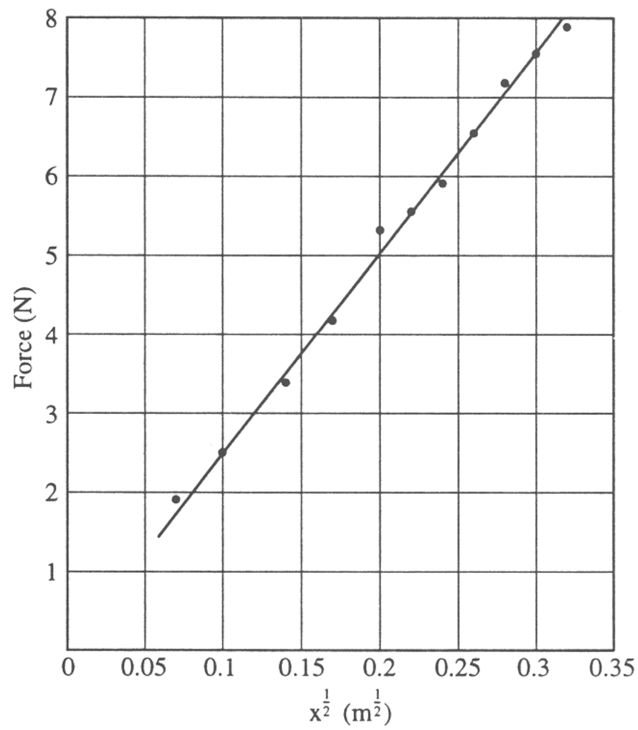
Time—45 minutes

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

Mech 1. A nonlinear spring is compressed horizontally. The spring exerts a force that obeys the equation $F(x) = Ax^{1/2}$, where x is the distance from equilibrium that the spring is compressed and A is a constant. A physics student records data on the force exerted by the spring as it is compressed and plots the two graphs below, which include the data and the student's best-fit curves.





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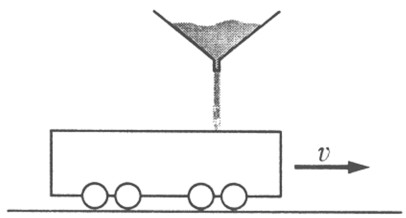
(a) From one or both of the given graphs, determine A. Be sure to show your work and specify the units.

(b) i. Determine an expression for the work done in compressing the spring a distance x.

ii. Explain in a few sentences how you could use one or both of the graphs to estimate a numerical answer to part (b) i for a given value of x.

(c) The spring is mounted horizontally on a countertop that is 1.3 m high so that its equilibrium position is just at the edge of the countertop. The spring is compressed so that it stores 0.2 J of energy and is then used to launch a ball of mass 0.10 kg horizontally from the countertop. Neglecting friction, determine the horizontal distance d from the edge of the countertop to the point where the ball strikes the floor.



Mech 2. An open-top railroad car (initially empty and of mass M_0) rolls with negligible friction along a straight horizontal track and passes under the spout of a sand conveyor. When the car is under the conveyor, sand is dispensed from the conveyor in a narrow stream at a steady rate $\Delta M/\Delta t = C$ and falls vertically from an average height h above the floor of the railroad car. The car has initial speed v_0 and sand is filling it from time $t = 0$ to $t = T$. Express your answers to the following in terms of the given quantities and g.

(a) Determine the mass M of the car plus the sand that it catches as a function of time t for $0 < t < T$.

(b) Determine the speed v of the car as a function of time t for $0 < t < T$.

(c) i. Determine the initial kinetic energy K_i of the empty car.

ii. Determine the final kinetic energy K_f of the car and its load.

iii. Is kinetic energy conserved? Explain why or why not.

(d) Determine expressions for the normal force exerted on the car by the tracks at the following times.

i. Before $t = 0$

ii. For $0 < t < T$

iii. After $t = T$

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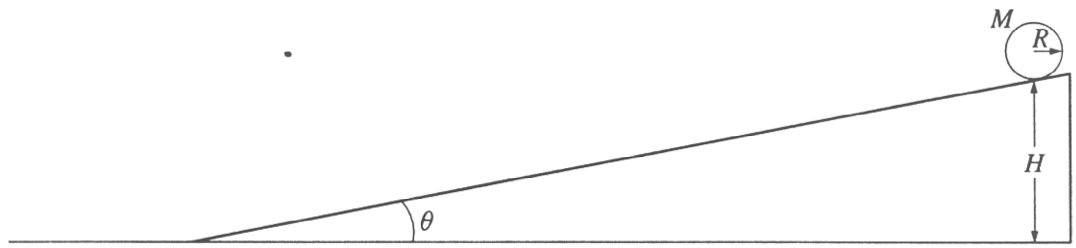
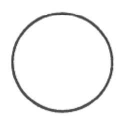


Mech 3. A solid cylinder with mass M, radius R, and rotational inertia $\frac{1}{2}MR^2$ rolls without slipping down the inclined plane shown above. The cylinder starts from rest at a height H. The inclined plane makes an angle θ with the horizontal. Express all solutions in terms of M, R, H, θ, and g.

(a) Determine the translational speed of the cylinder when it reaches the bottom of the inclined plane.

(b) On the figure below, draw and label the forces acting on the cylinder as it rolls down the inclined plane. Your arrows should begin at the point of application of each force.



(c) Show that the acceleration of the center of mass of the cylinder while it is rolling down the inclined plane is $\frac{2}{3}g \sin \theta$.

(d) Determine the minimum coefficient of friction between the cylinder and the inclined plane that is required for the cylinder to roll without slipping.

(e) The coefficient of friction μ is now made less than the value determined in part (d), so that the cylinder both rotates and slips.

i. Indicate whether the translational speed of the cylinder at the bottom of the inclined plane is greater than, less than, or equal to the translational speed calculated in part (a). Justify your answer.

ii. Indicate whether the total kinetic energy of the cylinder at the bottom of the inclined plane is greater than, less than, or equal to the total kinetic energy for the previous case of rolling without slipping. Justify your answer.

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.

NO TEST MATERIAL ON THIS PAGE

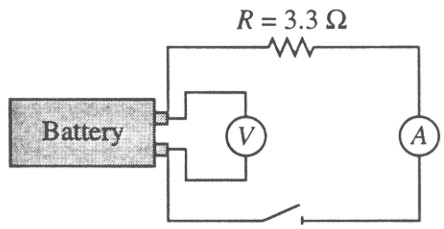
PHYSICS C

SECTION II, ELECTRICITY AND MAGNETISM

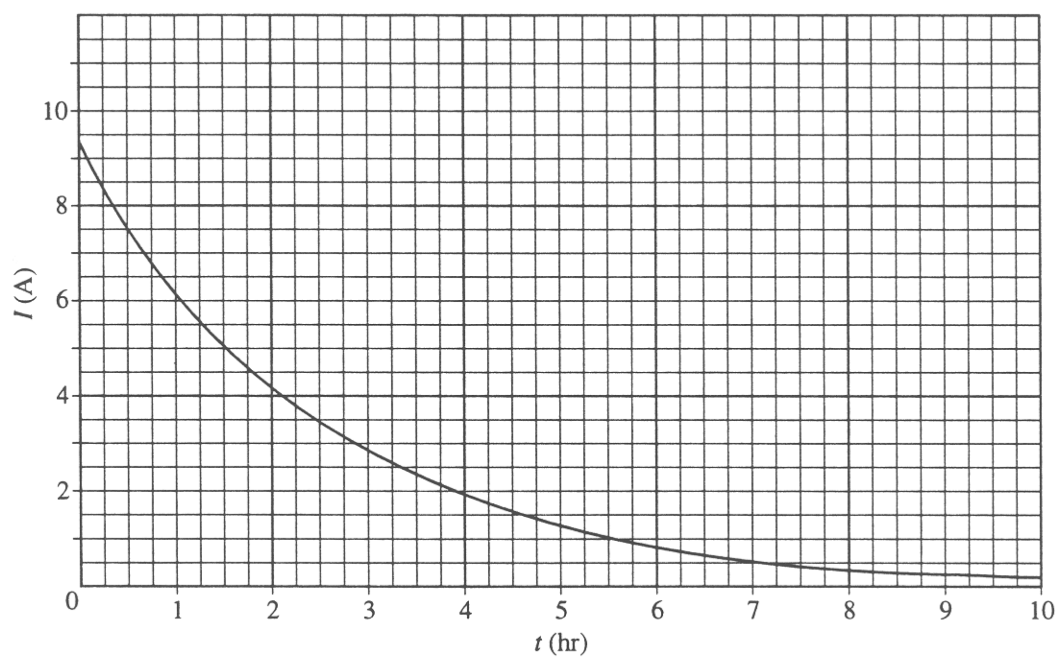
Time—45 minutes

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



E & M 1. A technician uses the circuit shown above to test prototypes of a new battery design. The switch is closed, and the technician records the current for a period of time. The curve that best fits the results is shown in the graph below.



The equation for this curve is $I = I_0 e^{-kt}$, where t is the time elapsed from the instant the switch is closed and I_0 and k are constants.

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(a) i. Using the information in the graph, determine the potential difference V_0 across the resistor immediately after the switch is closed.

ii. Would the open circuit voltage of the fresh battery have been less than, greater than, or equal to the value in part i? Justify your answer.

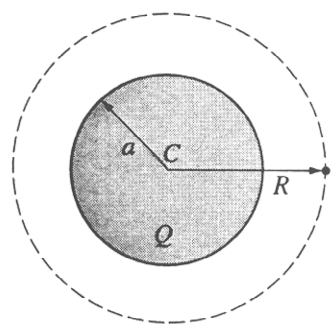
(b) Determine the value of k from this best-fit curve. Show your work and be sure to include units in your answer.

(c) Determine the following in terms of R, I_0, k, and t.

i. The power delivered to the resistor at time $t = 0$

ii. The power delivered to the resistor as a function of time t

iii. The total energy delivered to the resistor from $t = 0$ until the current is reduced to zero



E & M 2. A nonconducting sphere with center C and radius a has a spherically symmetric electric charge density. The total charge of the object is $Q > 0$.

(a) Determine the magnitude and direction of the electric field at point P, which is a distance $R > a$ to the right of the sphere's center.

(b) Determine the flux of the electric field through the spherical surface centered at C and passing through P.

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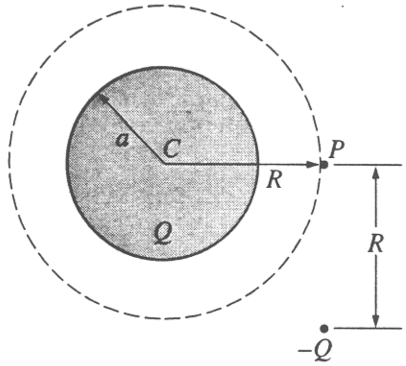
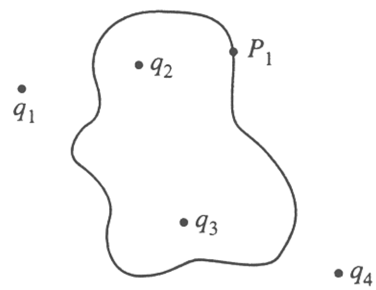


A point particle of charge $-Q$ is now placed a distance R below point P, as shown above.

(c) Determine the magnitude and direction of the electric field at point P.



(d) Now consider four point charges, q_1, q_2, q_3, and q_4, that lie in the plane of the page as shown in the diagram above. Imagine a three-dimensional closed surface whose cross section in the plane of the page is indicated.

i. Which of these charges contribute to the net electric flux through the surface?

ii. Which of these charges contribute to the electric field at point P_1 ?

iii. Are your answers to i and ii the same or are they different?
Explain why this is so.

(e) If the net charge enclosed by a surface is zero, does this mean that the field is zero at all points on the surface? Justify your answer.

(f) If the field is zero at all points on a surface, does this mean there is no net charge enclosed by the surface? Justify your answer.

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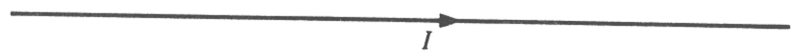
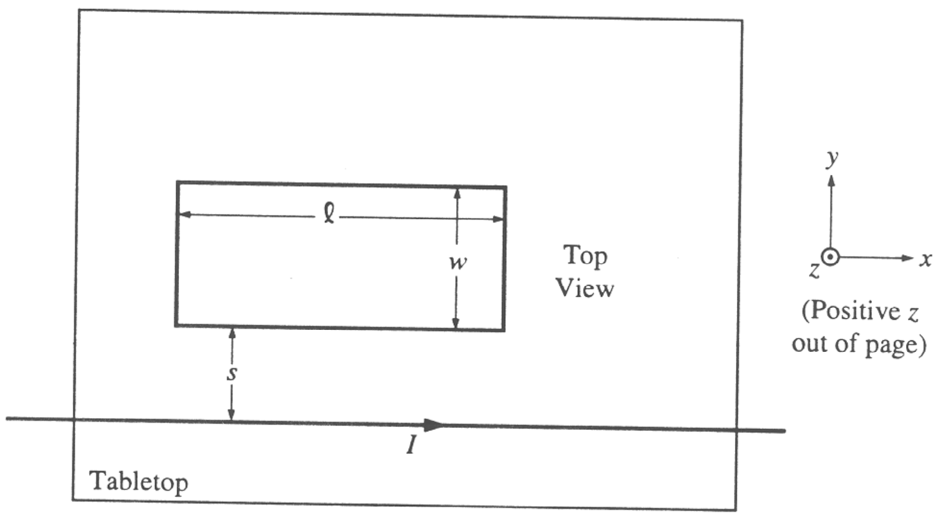


E & M 3. A long, straight wire lies on a table and carries a constant current I, as shown above.

(a) Using Ampere's law, derive an expression for the magnitude B of the magnetic field at a perpendicular distance r from the wire.

A rectangular loop of wire of length ℓ, width w, and resistance R is placed on the table a distance s from the wire, as shown below.



(b) What is the direction of the magnetic field passing through the rectangular loop relative to the coordinate axes shown above on the right?

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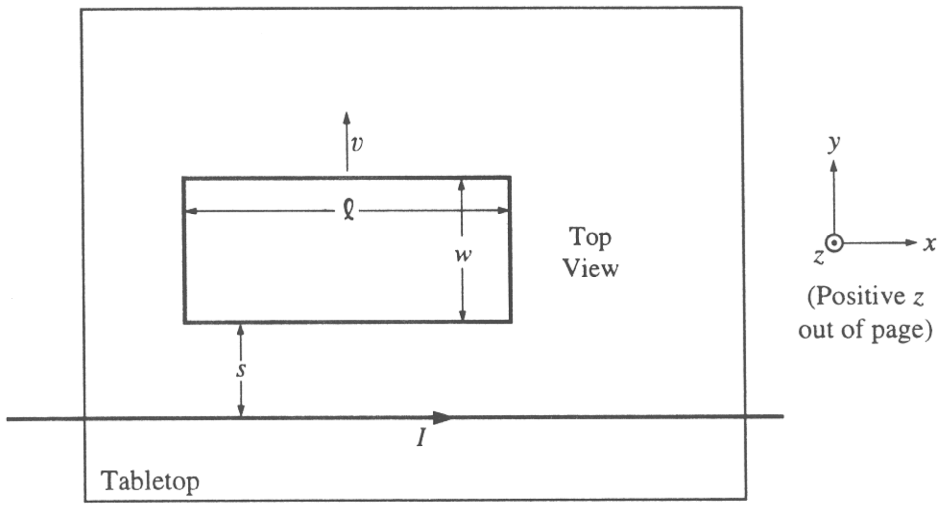
(c) Show that the total magnetic flux ϕ_m through the rectangular loop is $\frac{\mu_0 I \ell}{2\pi}\ln\left(\frac{s + w}{s}\right)$.



The rectangular loop is now moved along the tabletop directly away from the wire at a constant speed $v = \left|\frac{ds}{dt}\right|$, as shown above.

(d) What is the direction of the current induced in the loop? Briefly explain your reasoning.

(e) What is the direction of the net magnetic force exerted by the wire on the moving loop relative to the coordinate axes shown above on the right? Briefly explain your reasoning.

(f) Determine the current induced in the loop. Express your answer in terms of the given quantities and fundamental constants.

STOP

END OF SECTION II, ELECTRICITY AND MAGNETISM

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