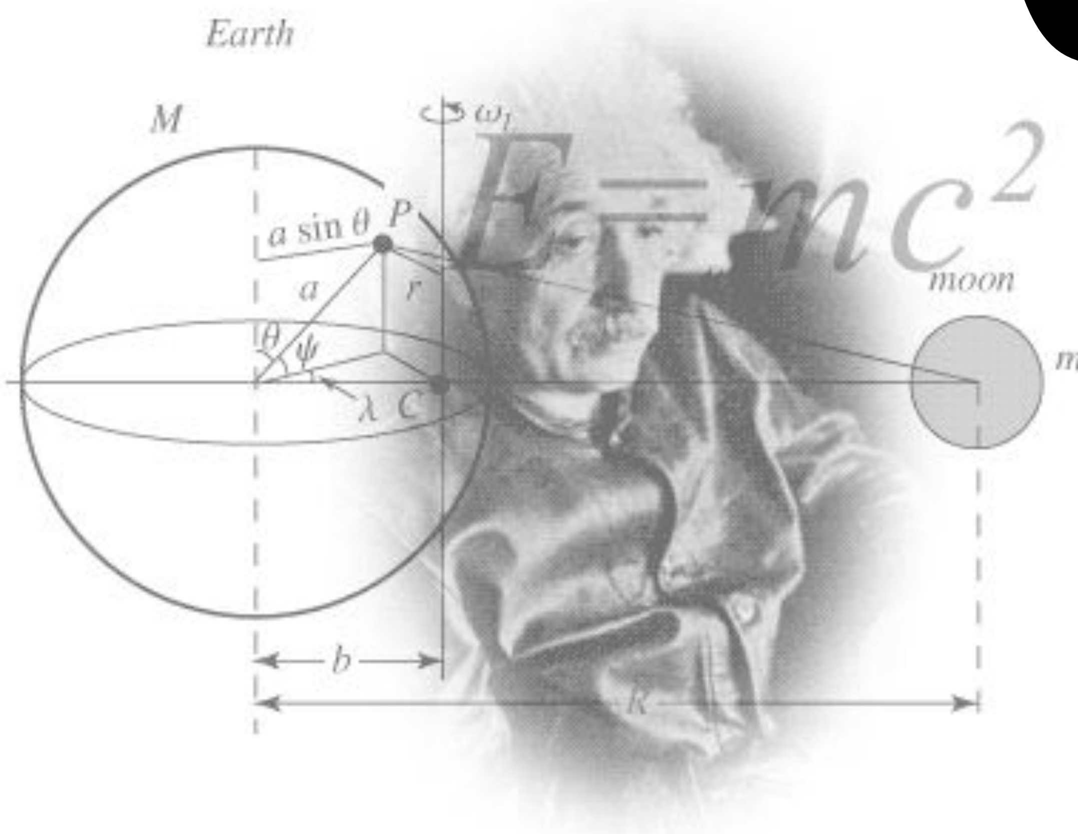
AP Physics C – Practice Workbook – Book 2
Electricity and Magnetism

C



2012-2013

Table of Contents

This book is a compilation of all the problems published by College Board in AP Physics C organized by topic.

The problems vary in level of difficulty and type and this book represents an invaluable resource for practice and review and should be used… often. Whether you are struggling or confident in a topic, you should be doing these problems as a reinforcement of ideas and concepts on a scale that could never be covered in the class time allotted.

The answers as presented are not the only method to solving many of these problems and physics teachers may present slightly different methods and/or different symbols and variables in each topic, but the underlying physics concepts are the same and we ask you read the solutions with an open mind and use these differences to expand your problem solving skills.

Finally, we *are* fallible and if you find any typographical errors, formatting errors or anything that strikes you as unclear or unreadable, please let us know so we can make the necessary announcements and corrections.

CollegeBoard AP

Table of Information and Equation Tables for AP Physics Exams

The accompanying Table of Information and Equation Tables will be provided to students when they take the AP Physics Exams. Therefore, students may NOT bring their own copies of these tables to the exam room, although they may use them throughout the year in their classes in order to become familiar with their content. **Check the Physics course home pages on AP Central for the latest versions of these tables (apcentral.collegeboard.com).**

Table of Information

For both the Physics B and Physics C Exams, the Table of Information is printed near the front cover of the multiple-choice section and on the green insert provided with the free-response section. The tables are identical for both exams except for one convention as noted.

Equation Tables

For both the Physics B and Physics C Exams, the equation tables for each exam are printed only on the green insert provided with the free-response section. The equation tables may be used by students when taking the free-response sections of both exams but NOT when taking the multiple-choice sections.

The equations in the tables express the relationships that are encountered most frequently in AP Physics courses and exams. However, the tables do not include all equations that might possibly be used. For example, they do not include many equations that can be derived by combining other equations in the tables. Nor do they include equations that are simply special cases of any that are in the tables. Students are responsible for understanding the physical principles that underlie each equation and for knowing the conditions for which each equation is applicable.

The equation tables are grouped in sections according to the major content category in which they appear. Within each section, the symbols used for the variables in that section are defined. However, in some cases the same symbol is used to represent different quantities in different tables. It should be noted that there is no uniform convention among textbooks for the symbols used in writing equations. The equation tables follow many common conventions, but in some cases consistency was sacrificed for the sake of clarity.

Some explanations about notation used in the equation tables:

1. The symbols used for physical constants are the same as those in the Table of Information and are defined in the Table of Information rather than in the right-hand columns of the tables.
2. Symbols in bold face represent vector quantities.
3. Subscripts on symbols in the equations are used to represent special cases of the variables defined in the right-hand columns.
4. The symbol Δ before a variable in an equation specifically indicates a change in the variable (i.e., final value minus initial value).
5. Several different symbols (e.g., d, r, s, h, ℓ) are used for linear dimensions such as length. The particular symbol used in an equation is one that is commonly used for that equation in textbooks.

TABLE OF INFORMATION DEVELOPED FOR 2012 (see note on cover page)

CONSTANTS AND CONVERSION FACTORS

Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	1 electron volt, $1\text{ eV} = 1.60 \times 10^{-19}$ J
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Speed of light, $c = 3.00 \times 10^{8}$ m/s
Avogadro's number, $N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant, $G = 6.67 \times 10^{-11}$ m^3/kg•s^2
Universal gas constant, $R = 8.31$ J/(mol•K)	Acceleration due to gravity at Earth's surface, $g = 9.8$ m/s^2
Boltzmann's constant, $k_B = 1.38 \times 10^{-23}$ J/K	

1 unified atomic mass unit,	$1\text{ u} = 1.66 \times 10^{-27}\text{ kg} = 931\text{ MeV}/c^2$
Planck's constant,	$h = 6.63 \times 10^{-34}\text{ J•s} = 4.14 \times 10^{-15}\text{ eV•s}$
	$hc = 1.99 \times 10^{-25}\text{ J•m} = 1.24 \times 10^{3}\text{ eV•nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}\text{ C}^2/\text{N•m}^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^{9}\text{ N•m}^2/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}\text{ (T•m)/A}$
Magnetic constant,	$k' = \mu_0/4\pi = 1 \times 10^{-7}\text{ (T•m)/A}$
1 atmosphere pressure,	$1\text{ atm} = 1.0 \times 10^{5}\text{ N/m}^2 = 1.0 \times 10^{5}\text{ Pa}$

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 conventions are used in this exam.

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.

*Not on the Table of Information for Physics C, since Thermodynamics is not a Physics C topic.

ADVANCED PLACEMENT PHYSICS B EQUATIONS DEVELOPED FOR 2012

NEWTONIAN MECHANICS

$$\upsilon = \upsilon_0 + at$$

$$x = x_0 + \upsilon_0 t + \frac{1}{2}at^2$$

$$\upsilon^2 = \upsilon_0^2 + 2a(x - x_0)$$

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

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

$$a_c = \frac{\upsilon^2}{r}$$

$$\tau = rF\sin\theta$$

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

$$\mathbf{J} = \mathbf{F}\Delta t = \Delta\mathbf{p}$$

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

$$\Delta U_g = mgh$$

$$W = F\Delta r\cos\theta$$

$$P_{avg} = \frac{W}{\Delta t}$$

$$P = F\upsilon\cos\theta$$

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

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

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

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

$$T = \frac{1}{f}$$

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

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

a = acceleration
F = force
f = frequency
h = height
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
m = mass
N = normal force
P = power
p = momentum
r = radius or distance
T = period
t = time
U = potential energy
υ = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque

ELECTRICITY AND MAGNETISM

$$F = \frac{kq_1q_2}{r^2}$$

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

$$U_E = qV = \frac{kq_1q_2}{r}$$

$$E_{avg} = -\frac{V}{d}$$

$$V = k\left(\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} + \ldots\right)$$

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

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

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

$$I_{avg} = \frac{\Delta Q}{\Delta t}$$

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

$$V = IR$$

$$P = IV$$

$$C_p = C_1 + C_2 + C_3 + \ldots$$

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots$$

$$R_s = R_1 + R_2 + R_3 + \ldots$$

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

$$F_B = q\upsilon B\sin\theta$$

$$F_B = BI\ell\sin\theta$$

$$B = \frac{\mu_0}{2\pi}\frac{I}{r}$$

$$\phi_m = BA\cos\theta$$

$$\varepsilon_{avg} = -\frac{\Delta\phi_m}{\Delta t}$$

$$\varepsilon = B\ell\upsilon$$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
ε = emf
F = force
I = current
ℓ = length
P = power
Q = charge
q = point charge
R = resistance
r = distance
t = time
U = potential (stored) energy
V = electric potential or potential difference
υ = velocity or speed
ρ = resistivity
θ = angle
ϕ_m = magnetic flux

ADVANCED PLACEMENT PHYSICS B EQUATIONS DEVELOPED FOR 2012

FLUID MECHANICS AND THERMAL PHYSICS

$\rho = m/V$

$P = P_0 + \rho g h$

$F_{buoy} = \rho V g$

$A_1 \upsilon_1 = A_2 \upsilon_2$

$P + \rho g y + \frac{1}{2}\rho \upsilon^2 = \text{const.}$

$\Delta \ell = \alpha \ell_0 \Delta T$

$H = \frac{kA\Delta T}{L}$

$P = \frac{F}{A}$

$PV = nRT = Nk_B T$

$K_{avg} = \frac{3}{2} k_B T$

$\upsilon_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$

$W = -P\Delta V$

$\Delta U = Q + W$

$e = \left|\frac{W}{Q_H}\right|$

$e_c = \frac{T_H - T_C}{T_H}$

A = area
e = efficiency
F = force
h = depth
H = rate of heat transfer
k = thermal conductivity
K_{avg} = average molecular kinetic energy
ℓ = length
L = thickness
m = mass
M = molar mass
n = number of moles
N = number of molecules
P = pressure
Q = heat transferred to a system
T = temperature
U = internal energy
V = volume
υ = velocity or speed
υ_{rms} = root-mean-square velocity
W = work done on a system
y = height
α = coefficient of linear expansion
μ = mass of molecule
ρ = density

ATOMIC AND NUCLEAR PHYSICS

$E = hf = pc$

$K_{\max} = hf - \phi$

$\lambda = \frac{h}{p}$

$\Delta E = (\Delta m)c^2$

E = energy
f = frequency
K = kinetic energy
m = mass
p = momentum
λ = wavelength
ϕ = work function

WAVES AND OPTICS

$\upsilon = f\lambda$

$n = \frac{c}{\upsilon}$

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$\sin\theta_c = \frac{n_2}{n_1}$

$\frac{1}{s_i} + \frac{1}{s_0} = \frac{1}{f}$

$M = \frac{h_i}{h_0} = -\frac{s_i}{s_0}$

$f = \frac{R}{2}$

$d\sin\theta = m\lambda$

$x_m \approx \frac{m\lambda L}{d}$

d = separation
f = frequency or focal length
h = height
L = distance
M = magnification
m = an integer
n = index of refraction
R = radius of curvature
s = distance
υ = speed
x = position
λ = wavelength
θ = angle

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

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

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

Rectangular Solid
$V = \ell wh$

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

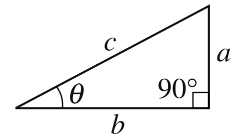
Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

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

ADVANCED PLACEMENT PHYSICS C EQUATIONS DEVELOPED FOR 2012

MECHANICS

$$\upsilon = \upsilon_0 + at$$

$$x = x_0 + \upsilon_0 t + \frac{1}{2}at^2$$

$$\upsilon^2 = \upsilon_0{}^2 + 2a(x - x_0)$$

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

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

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

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

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

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

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

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

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

$$\Delta U_g = mgh$$

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

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

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

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

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

$$\upsilon = r\omega$$

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

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

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

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

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
υ = 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

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

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

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

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

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

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

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

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

ELECTRICITY AND MAGNETISM

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

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

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

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

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

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

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

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

$$C_p = \sum_i C_i$$

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

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

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

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

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

$$I = Nev_d A$$

$$V = IR$$

$$R_s = \sum_i R_i$$

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

$$P = IV$$

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

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 = distance
t = time
U = potential or stored energy
V = electric potential
υ = velocity or speed
ρ = resistivity
ϕ_m = magnetic flux
κ = dielectric constant

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

$$d\mathbf{B} = \frac{\mu_0}{4\pi}\frac{I\,d\boldsymbol{\ell} \times \mathbf{r}}{r^3}$$

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

$$B_s = \mu_0 nI$$

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

$$\mathcal{E} = \oint \mathbf{E} \bullet d\boldsymbol{\ell} = -\frac{d\phi_m}{dt}$$

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

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

ADVANCED PLACEMENT PHYSICS C EQUATIONS DEVELOPED FOR 2012

GEOMETRY AND TRIGONOMETRY

Rectangle

$A = bh$

Triangle

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

Circle

$A = \pi r^2$

$C = 2\pi r$

Rectangular Solid

$V = \ell wh$

Cylinder

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

Sphere

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

$S = 4\pi r^2$

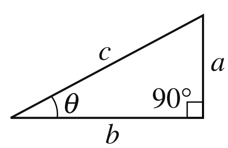
Right Triangle

$a^2 + b^2 = c^2$

$\sin\theta = \frac{a}{c}$

$\cos\theta = \frac{b}{c}$

$\tan\theta = \frac{a}{b}$



A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

CALCULUS

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

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

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

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

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

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

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

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

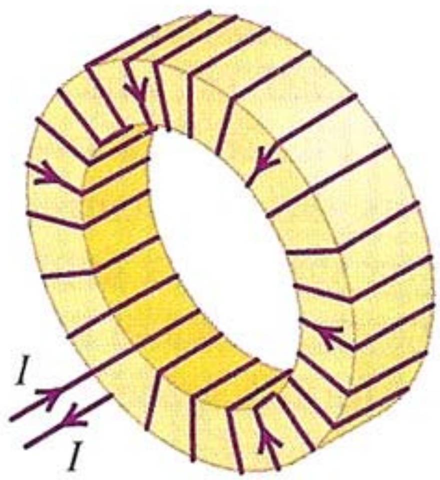
$$\int \frac{dx}{x} = \ln|x|$$

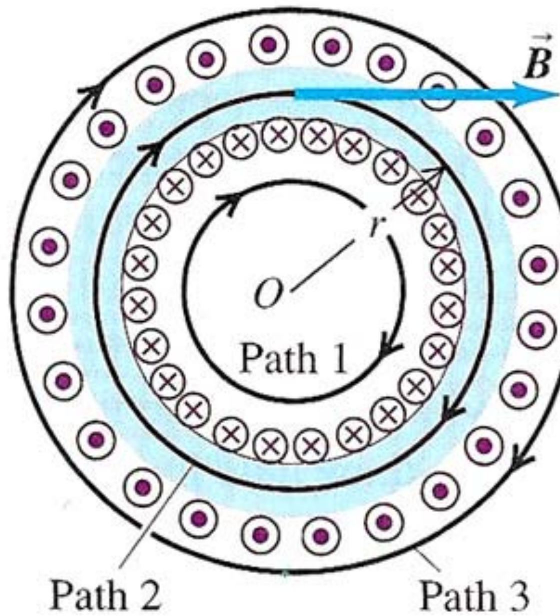
$$\int \cos x\,dx = \sin x$$

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

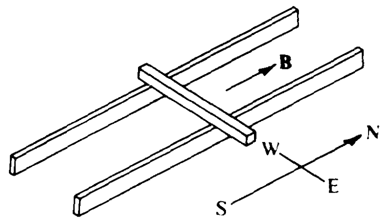
Chapter 10

Magnetism





SECTION A – Magnetostatics



1. The ends of a metal bar rest on two horizontal north-south rails as shown above. The bar may slide without friction freely with its length horizontal and lying east and west as shown above. There is a magnetic field parallel to the rails and directed north. A battery is connected between the rails and causes the electrons in the bar to drift to the east. The resulting magnetic force on the bar is directed
(A) north (B) south (C) east (D) west (E) vertically

2. A charged particle is projected with its initial velocity parallel to a uniform magnetic field. The resulting path is a
(A) spiral
(B) parabolic arc
(C) circular arc
(D) straight line parallel to the field
(E) straight line perpendicular to the field

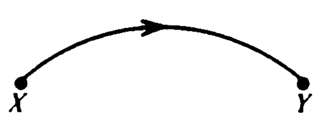
Questions 3-4

A proton traveling with speed *v* enters a uniform electric field of magnitude *E*, directed parallel to the plane of the page, as shown in the figure above. There is also a magnetic force on the proton that is in the direction opposite to that of the electric force.

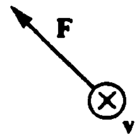
3. Which of the following is a possible direction for the magnetic field?

(A) ↓ (B) ↑ (C) ← (D) ⊙ (directed out of the page) (E) ⊗(directed into the page

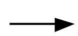
4. If e represents the magnitude of the proton charge, what minimum magnitude of the magnetic field could balance the electric force on the proton?
(A) E/v (B) eE/v (C) vE (D) eE (E) evE

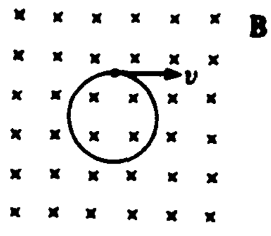


5. At point X a charged particle has a kinetic energy of 9 microjoules (μJ). It follows the path shown above from X to Y through a region in which there is an electric field and a magnetic field. At Y the particle has a kinetic energy of 11 μJ. What is the work done by the magnetic field on the particle?
(A) 11 μJ (B) 2 μJ (C) - 2 μJ (D) - 11 μJ (E) None of the above

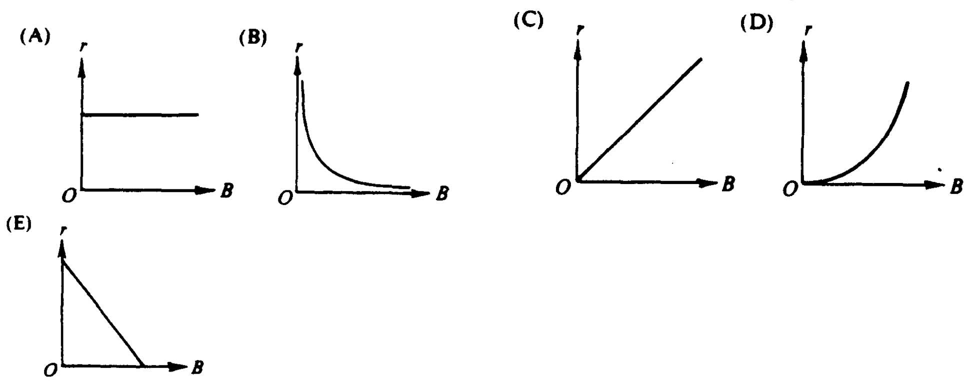


6. In a region of space there is a uniform **B** field in the plane of the page but no **E** field. A positively charged particle with velocity **v** directed into the page is subject to a force **F** in the plane of the page as shown above. Which of the following vectors best represents the direction of **B**?

(A)  (B)  (C)  (D)  (E) 



7. A negatively charged particle in a uniform magnetic field **B** moves with constant speed v in a circular path of radius r, as shown above. Which of the following graphs best represents the radius r as a function of the magnitude of **B**, if the speed v is constant?



8. Which of the following equations implies that it is impossible to isolate a magnetic pole?

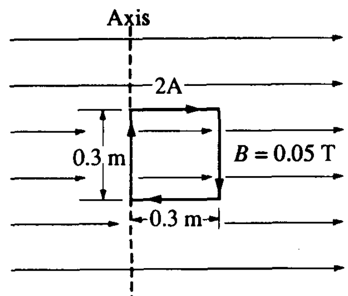
(A) $\oint E \circ dA = q / \varepsilon_0$

(B) $\oint E \circ dl = -d\phi_E / dt$

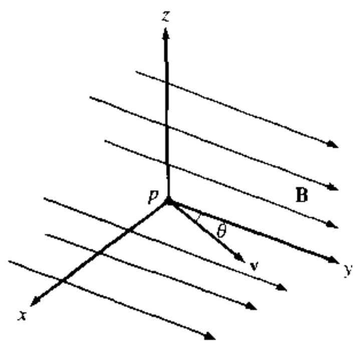
(C) $\oint B \circ dA = 0$

(D) $\oint B \circ dl = \mu_0 i + \mu_0 \varepsilon_0 d\phi_E / dt$

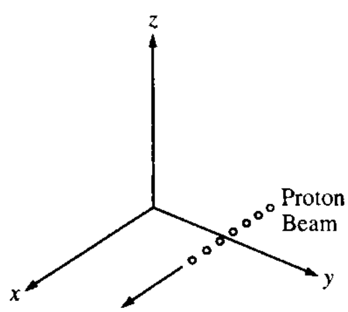
(E) None of the above



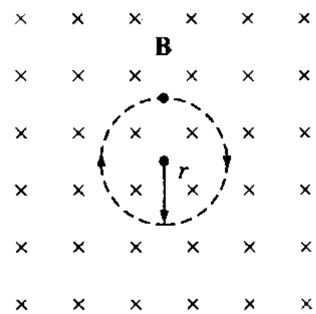
9. A square loop of wire 0.3 meter on a side carries a current of 2 amperes and is located in a uniform 0.05-tesla magnetic field. The left side of the loop is aligned along and attached to a fixed axis. When the plane of the loop is parallel to the magnetic field in the position shown above, what is the magnitude of the torque exerted on the loop about the axis?
A) 0.00225 Nm B) 0.0090 Nm C) 0.278 Nm D) 1.11 Nm E) 111 Nm



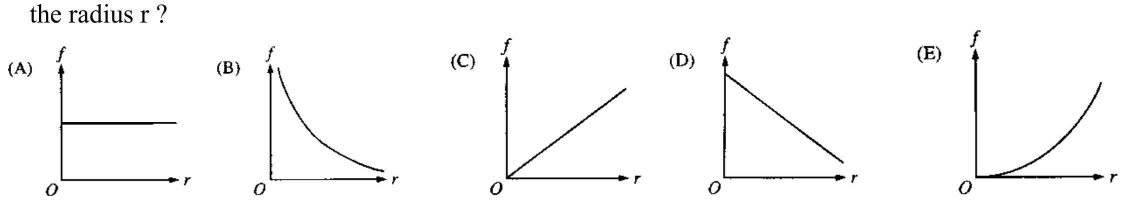
10. A uniform magnetic field **B** is parallel to the xy-plane and in the +y-direction, as shown above. A proton p initially moves with velocity **v** in the xy-plane at an angle θ to the magnetic field and the y-axis. The proton will subsequently follow what kind of path?
(A) A straight-line path in the direction of **v**
(B) A circular path in the xy-plane
(C) A circular path in the yz-plane
(D) A helical path with its axis parallel to the y-axis
(E) A helical path with its axis parallel to the z-axis



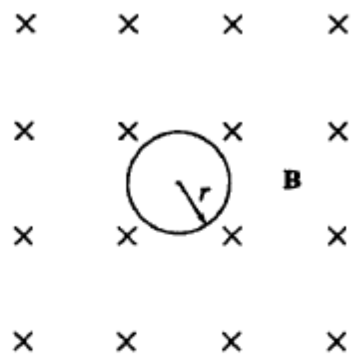
11. A beam of protons moves parallel to the x-axis in the positive x-direction, as shown above, through a region of crossed electric and magnetic fields balanced for zero deflection of the beam. If the magnetic field is pointed in the positive y-direction, in what direction must the electric field be pointed?
(A) Positive y-direction (B) Positive z-direction (C) Negative x-direction (D) Negative y-direction
(E) Negative z-direction



12. A negatively charged particle in a uniform magnetic field B moves in a circular path of radius r, as shown above. Which of the following graphs best depicts how the frequency of revolution f of the particle depends on the radius r ?



Questions 13-14



A particle of charge +e and mass m moves with speed v perpendicular to a uniform magnetic field **B** directed into the page. The path of the particle is a circle of radius *r*, as shown above.

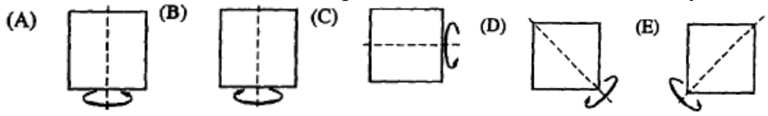
13. Which of the following correctly gives the direction of motion and the equation relating *v* and *r*?

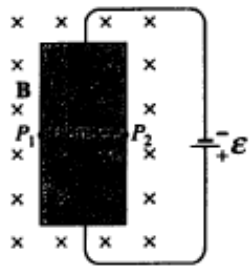
	Direction	Equation
(A)	Clockwise	$eBr = mv$
(B)	Clockwise	$eBr = mv^2$
(C)	Counterclockwise	$eBr = mv$
(D)	Counterclockwise	$eBr = mv^2$
(E)	Counterclockwise	$eBr^2 = mv^2$

14. The period of revolution of the particle is
(A) mr/eB (B) $\sqrt{m/eB}$ (C) $2\pi m/eB$ (D) $2\pi\sqrt{m/eB}$ (E) $2\pi\sqrt{mr/eB}$

15. A charged particle can move with constant velocity through a region containing both an electric field and a magnetic field only if the
(A) electric field is parallel to the magnetic field
(B) electric field is perpendicular to the magnetic field
(C) electric field is parallel to the velocity vector
(D) magnetic field is parallel to the velocity vector
(E) magnetic field is perpendicular to the velocity vector

16. A square loop of wire carrying a current I is initially in the plane of the page and is located in a uniform magnetic field B that points toward the bottom of the page, as shown above. Which of the following shows the correct initial rotation of the loop due to the force exerted on it by the magnetic field?



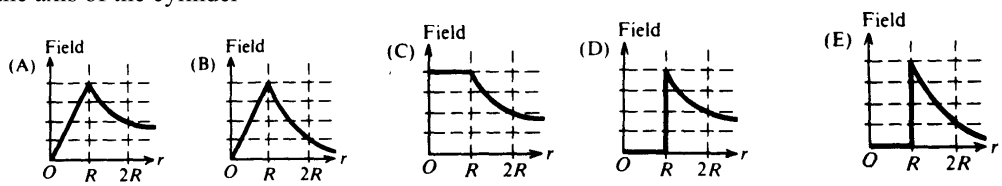


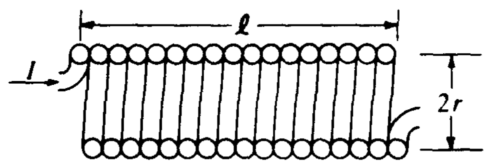
17. A sheet of copper in the plane of the page is connected to a battery as shown above, causing electrons to drift through the copper toward the bottom of the page. The copper sheet is in a magnetic field **B** directed into the page. P_1 and P_2 are points at the edges of the strip. Which of the following statements is true?
(A) P_1 is at a higher potential than P_2.
(B) P_2 is at a higher potential than P_1.
(C) P_1 and P_2 are at equal positive potential.
(D) P_1 and P_2 are at equal negative potential.
(E) Current will cease to flow in the copper sheet.

SECTION B – Biot Savart and Ampere's Law

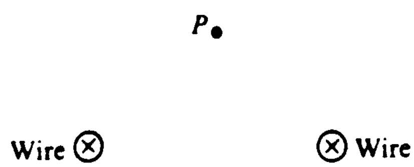
18. Two long, parallel wires, fixed in space, carry currents I_1 and I_2. The force of attraction has magnitude F. What currents will give an attractive force of magnitude 4F?
(A) $2I_1$ and $\frac{1}{2}I_2$
(B) I_1 and $\frac{1}{4}I_2$
(C) $\frac{1}{2}I_1$ and $\frac{1}{2}I_2$
(D) $2I_1$ and $2I_2$
(E) $4I_1$ and $4I_2$

19. A solid cylindrical conductor of radius R carries a current I uniformly distributed throughout its interior. Which of the following graphs best represents the magnetic field intensity as a function of r, the radial distance from the axis of the cylinder

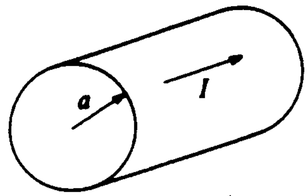




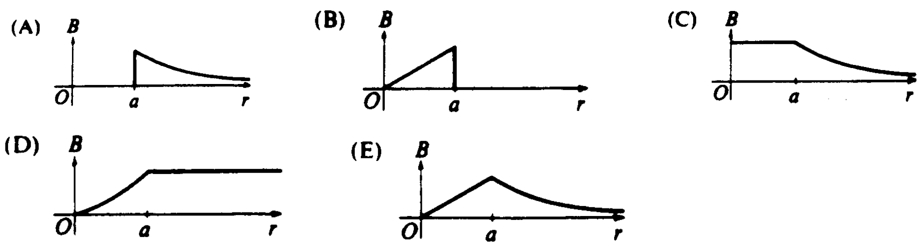
20. The cross section above shows a long solenoid of length l and radius r consisting of N closely wound turns of wire. When the current in the wire is I, the magnetic field within this solenoid has magnitude B_o. A solenoid with the same number of turns N, length l, and current I, but with radius 2r, would have a magnetic field of magnitude most nearly equal to
(A) $B_o/4$ (B) $B_o/2$ (C) B_o (D) $2B_o$ (E) $4B_o$



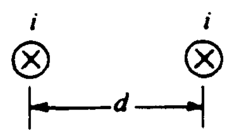
21. Two very long parallel wires carry equal currents in the same direction into the page, as shown above. At point P, which is 10 centimeters from each wire, the magnetic field is
(A) zero
(B) directed into the page
(C) directed out of the page
(D) directed to the left
(E) directed to the right



22. A current I, uniformly distributed over the cross section of a long cylindrical conductor of radius a, is directed as shown above. Which of the following graphs best represents the intensity B of the magnetic field as a function of the distance r from the axis of the cylinder?

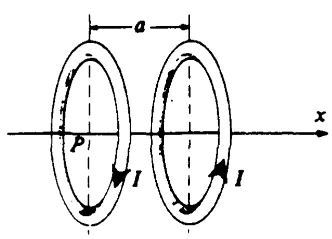


<u>Questions 23-24</u> relate to the two long parallel wires shown below. Initially the wires arc a distance d apart and each has a current i directed into the page. The force per unit length on each wire has magnitude F_o

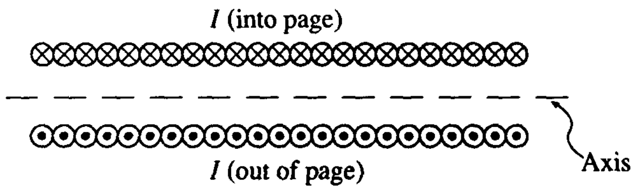


23. The direction of the force on the right-hand wire due to the current in the left-hand wire is
(A) to the right (B) to the left (C) upward in the plane of the page
(D) downward in the plane of the page (E) into the page

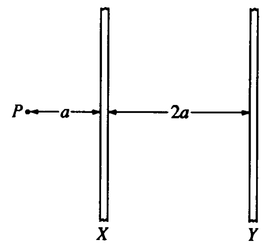
24. The wires are moved apart to a separation 2d and the current in each wire is increased to 2i. The new force per unit length on each wire is
(A) $F_0/4$ (B) $F_o/2$ (C) F_o (D) $2F_o$ (E) $4F_o$



25. Two identical parallel conducting rings have a common axis and are separated by a distance a, as shown above. The two rings each carry a current I, but in opposite directions. At point P, the center of the ring on the left the magnetic field due to these currents is
(A) zero (B) in the plane perpendicular to the x-axis (C) directed in the positive x-direction
(D) directed in the negative x-direction (E) none of the above



26. A cross section of a long solenoid that carries current I is shown above. All of the following statements about the magnetic field B inside the solenoid are correct EXCEPT:
    A) B is directed to the left.
    B) An approximate value for the magnitude of B may be determined by using Ampere's law.
    C) The magnitude of B is proportional to the current I.
    D) The magnitude of B is proportional to the number of turns of wire per unit length.
    E) The magnitude of B is proportional to the distance from the axis of the solenoid.



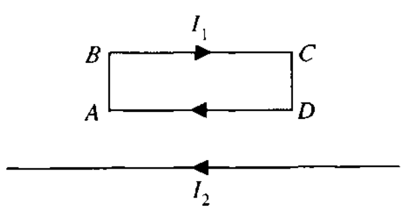
27. Two long parallel wires are a distance 2a apart, as shown above. Point P is in the plane of the wires and a distance a from wire X. When there is a current I in wire X and no current in wire Y, the magnitude of the magnetic field at P is B_o. When there are equal currents I in the same direction in both wires, the magnitude of the magnetic field at P is
    A) $2B_o/3$ B) B_o C) $10B_o/9$ D) $4B_o/3$ E) $2B_o$

Questions 28-29

A narrow beam of protons produces a current of 1.6×10^{-3} A. There are 10^9 protons in each meter along the beam.

28. Of the following, which is the best estimate of the average speed of the protons in the beam?
    (A) 10^{-15} m/s (B) 10^{-12} m/s (C) 10^{-7} m/s (D) 10^7 m/s (E) 10^{12} m/s

29. Which of the following describes the lines of magnetic field in the vicinity of the beam due to the beam's current?
    (A) Concentric circles around the beam (B) Parallel to the beam (C) Radial and toward the beam
    (D) Radial and away from the beam (E) There is no magnetic field.

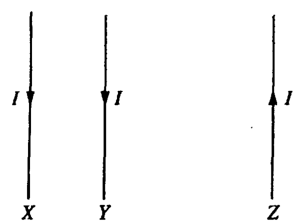


30. A rigid, rectangular wire loop ABCD carrying current I_1 lies in the plane of the page above a very long wire carrying current I_2 as shown above. The net force on the loop is
    (A) toward the wire (B) away from the wire (C) toward the left (D) toward the right (E) zero

31. In which of the following cases does there exist a nonzero magnetic field that can be conveniently determined by using Ampere's law?
(A) Outside a point charge that is at rest
(B) Inside a stationary cylinder carrying a uniformly distributed charge
(C) Inside a very long current-carrying solenoid
(D) At the center of a current-carrying loop of wire
(E) Outside a square current-carrying loop of wire

32. A wire of radius R has a current I uniformly distributed across its cross-sectional area. Ampere's law is used with a concentric circular path of radius r, with $r < R$, to calculate the magnitude of the magnetic field B at a distance r from the center of the wire. Which of the following equations results from a correct application of Ampere's law to this situation?
(A) $B(2\pi r) = \mu_0 I$ (B) $B(2\pi r) = \mu_0 I(r^2/R^2)$ (C) $B(2\pi r) = 0$ (D) $B(2\pi R) = \mu_0 I$ (E) $B(2\pi R) = \mu_0 I(r^2/R^2)$

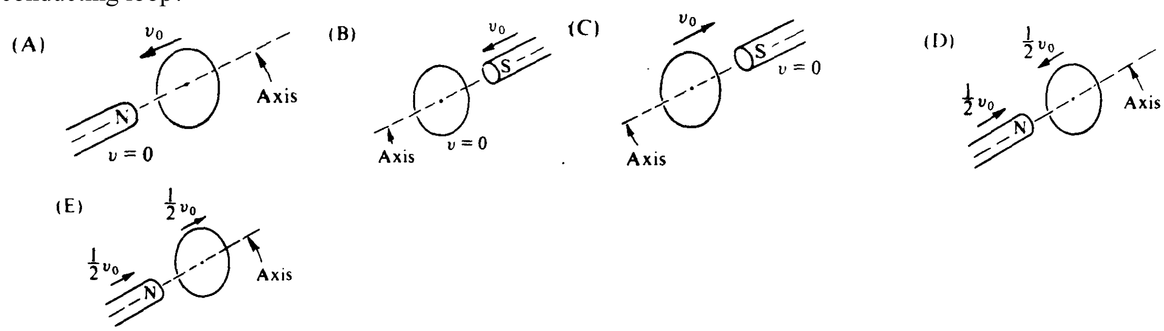
33. Two parallel wires, each carrying a current I, repel each other with a force F. If both currents are doubled, the force of repulsion is
A) 2F (B) $2\sqrt{2}$ F (C) 4F (D) $4\sqrt{2}$ F (E) 8F

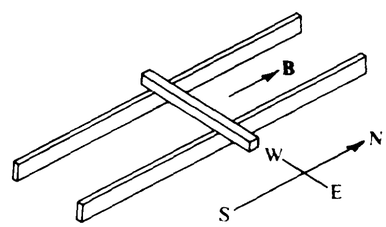


34. The currents in three parallel wires, X, Y, and Z, each have magnitude l and are in the directions shown above. Wire Y is closer to wire X than to wire Z. The magnetic force on wire Y is
(A) zero (B) into the page (C) out of the page (D) toward the bottom of the page (E) toward the left

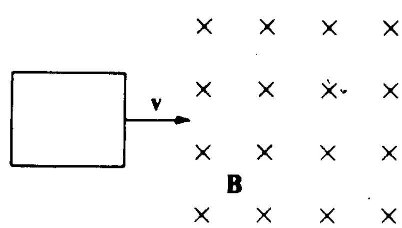
SECTION C – Induction and Inductance

35. In each of the following situations, a bar magnet is aligned along the axis of a conducting loop. The magnet and the loop move with the indicated velocities. In which situation will the bar magnet NOT induce a current in the conducting loop?

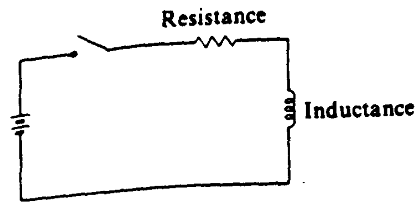




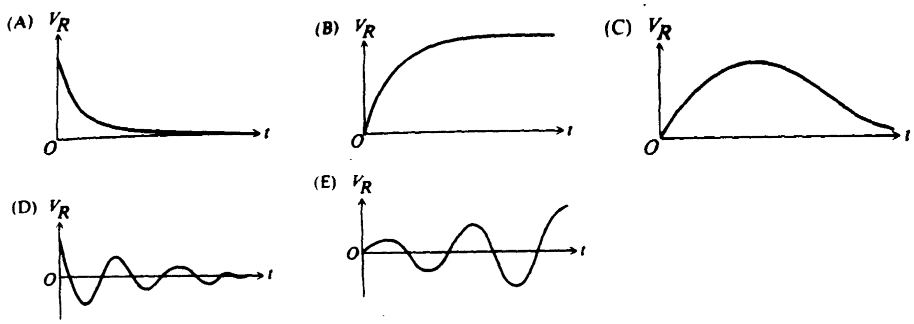
36. The ends of a metal bar rest on two horizontal north-south rails as shown above. The bar may slide without friction freely with its length horizontal and lying east and west as shown above. There is a magnetic field parallel to the rails and directed north. If the bar is pushed northward on the rails, the electromotive force induced in the bar as a result of the magnetic field will
(A) be directed upward
(B) be zero
(C) produce a westward current
(D) produce an eastward current
(E) stop the motion of the bar

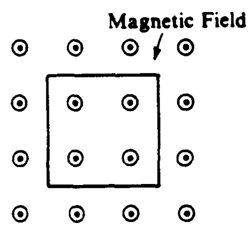


37. A loop of wire is pulled with constant velocity v to the right through a region of space where there is a uniform magnetic field B directed into the page, as shown above. The magnetic force on the loop is
(A) directed to the left both as it enters and as it leaves the region
(B) directed to the right both as it enters and as it leaves the region
(C) directed to the left as it enters the region and to the right as it leaves
(D) directed to the right as it enters the region and to the left as it leaves
(E) zero at all times



38. At time t = 0 the switch is closed in the circuit shown above. Which of the following graphs best describes the potential difference V, across the resistance as a function of time t ?

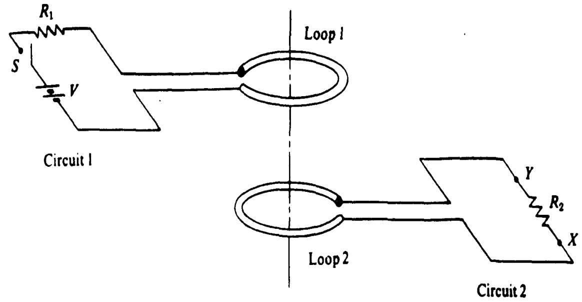




39. A square loop of wire of side 0.5 meter and resistance 10^{-2} ohm is located in a uniform magnetic field of intensity 0.4 tesla directed out of the page as shown above. The magnitude of the field is decreased to zero at a constant rate in 2 seconds. As the field is decreased, what are the magnitude and direction of the current in the loop?
(A) Zero (B) 5 A, counterclockwise (C) 5 A, clockwise
(D) 20 A, counterclockwise (E) 20 A, clockwise

40. If R is 1 ohm and L is 1 henry, then L/R is
(A) 1 volt (B) 1 farad (C) 1 ampere (D) 1 coulomb (E) 1 second

Questions 41-42 refer to the diagram below of two conducting loops having a common axis.

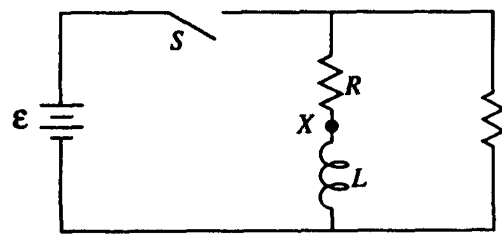


41. After the switch S is closed, the current through resistor R_2 is
    (A) from point X to point Y
    (B) from point Y to point X
    (C) zero at all times
    (D) oscillating with decreasing amplitude
    (E) oscillating with constant amplitude

42. After the switch S has been closed for a very long time, the currents in the two circuits are
    (A) zero in both circuits
    (B) zero in circuit 1 and V/R_2 in circuit 2
    (C) V/R_1 in circuit 1 and zero in circuit 2
    (D) V/R_1 in circuit I and V/R_2 in circuit 2
    (E) oscillating with constant amplitude in both circuits

43. A large parallel-plate capacitor is being charged and the magnitude of the electric field between the plates of the capacitor is increasing at the rate dE/dt. Which of the following statements is correct about the magnetic field in the region between the plates of the charging capacitor?
    A) It is parallel to the electric field.
    B) Its magnitude is directly proportional to dE/dt.
    C) Its magnitude is inversely proportional to dE/dt.
    D) Nothing about the field can be determined unless the charging current is known.
    E) Nothing about the field can be determined unless the instantaneous electric field is known.

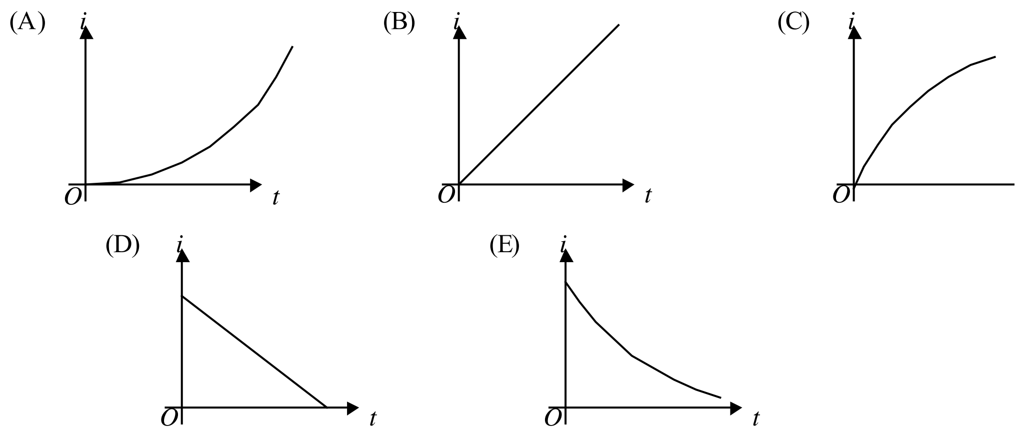
Questions 44-46 relate to the following circuit in which the switch S has been open for a long time.

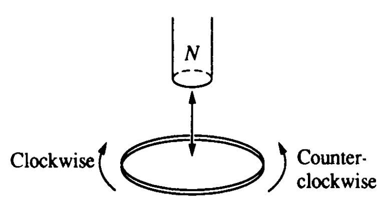


44. What is the instantaneous current at point X immediately after the switch is closed?
A) 0 B) $\mathcal{E}$/R C) $\mathcal{E}$/2R D) $\mathcal{E}$/RL E) $\mathcal{E}$L/2R

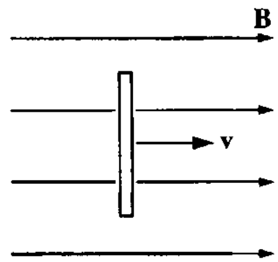
45. When the switch has been closed for a long time what is the energy stored in the inductor?
A) L$\mathcal{E}$/2R B) $L\mathcal{E}^2/2R^2$ C) $L\mathcal{E}^2/4R^2$ D) $LR^2/2\mathcal{E}^2$ E) $\mathcal{E}^2R^2/4L$

46. After the switch has been closed for a long time, it is opened at time t = 0. Which of the following graphs best represents the subsequent current i at point X as a function of time t ?



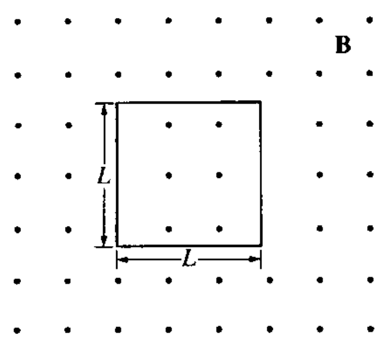


47. In the figure above, the north pole of the magnet is first moved down toward the loop of wire, then withdrawn upward. As viewed from above, the induced current in the loop is
A) always clockwise with increasing magnitude
B) always clockwise with decreasing magnitude
C) always counterclockwise with increasing magnitude
D) always counterclockwise with decreasing magnitude
E) first counterclockwise, then clockwise

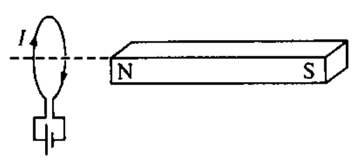


48. A vertical length of copper wire moves to the right with a steady velocity v in the direction of a constant horizontal magnetic field B as shown above. Which of the following describes the induced charges on the ends of the wire?

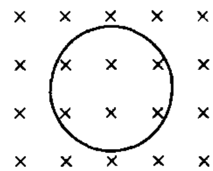
	Top End	Bottom End
(A)	Positive	Negative
(B)	Negative	Positive
(C)	Negative	Zero
(D)	Zero	Negative
(E)	Zero	Zero



49. A square wire loop with side L and resistance R is held at rest in a uniform magnetic field of magnitude B directed out of the page, as shown above. The field decreases with time t according to the equation $B = a - bt$, where a and b are positive constants. The current I induced in the loop is
(A) zero (B) aL^2/R, clockwise (C) aL^2/R, counterclockwise
(D) bL^2/R, clockwise (E) bL^2/R, counterclockwise



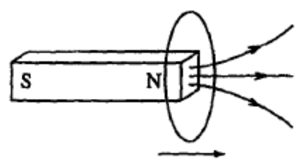
50. A bar magnet and a wire loop carrying current I are arranged as shown above. In which direction, if any, is the force on the current loop due to the magnet?
(A) Toward the magnet (B) Away from the magnet (C) Toward the top of the page
(D) Toward the bottom of the page (E) There is no force on the current loop.



51. A wire loop of area A is placed in a time-varying but spatially uniform magnetic field that is perpendicular to the plane of the loop, as shown above. The induced emf in the loop is given by $\mathcal{E} = bAt^{1/2}$, where b is a constant. The time varying magnetic field could be given by

(A) $\frac{1}{2}bAt^{-1/2}$ (B) $\frac{1}{2}bt^{-1/2}$ (C) $\frac{1}{2}bt^{1/2}$ (D) $\frac{2}{3}bAt^{3/2}$ (E) $\frac{2}{3}bt^{3/2}$

52. A circular current-carrying loop lies so that the plane of the loop is perpendicular to a constant magnetic field *of* strength B. Suppose that the radius R of the loop could be made to increase with time t so that $R = at$, where a *is* a constant. What is the magnitude of the emf that would be generated around the loop as a function of t?
(A) $2\pi Ba^2t$ (B) $2\pi Bat$ (C) $2\pi Bt$ (D) πBa^2t (E) $(\pi/3)Ba^2t^3$



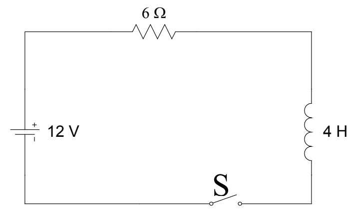
53. A conducting loop of wire that is initially around a magnet is pulled away from the magnet to the right, as indicated in the figure above, inducing a current in the loop. What is the direction of the force on the magnet and the direction of the magnetic field at the center of the loop due to the induced current?

	Direction of Force on the Magnet	Direction of Magnetic Field at Center of Loop due to Induced Current
(A)	To the right	To the right
(B)	To the right	To the left
(C)	To the left	To the right
(D)	To the left	To the left
(E)	No direction; the force is zero.	To the left

54. One of Maxwell's equations can be written as $\oint E \bullet ds = -\frac{d\phi}{dt}$. This equation expresses the fact that

(A) a changing magnetic field produces an electric field
(B) a changing electric field produces a magnetic field
(C) the net magnetic flux through a closed surface depends on the current inside
(D) the net electric flux through a closed surface depends on the charge inside
(E) electric charge is conserved

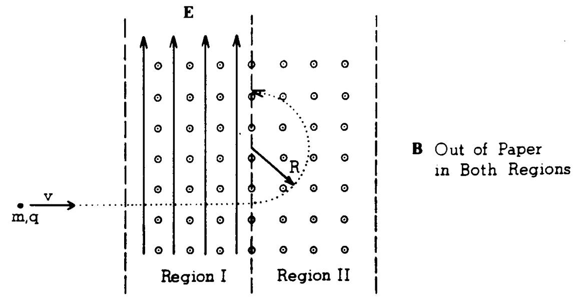
Questions 55-56 relate to the circuit represented below. The switch S, after being open for a long time, is then closed.



55. What is the current in the circuit after the switch has been closed a long time?
(A) 0 A (B) 1.2 A (C) 2 A (D) 3 A (E) 12 A

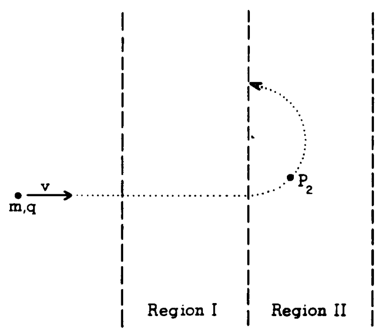
56. What is the potential difference across the resistor immediately after the switch is closed?
(A) 0 V (B) 2 V (C) 7.2 V (D) 8 V (E) 12 V

SECTION A – Magnetostatics



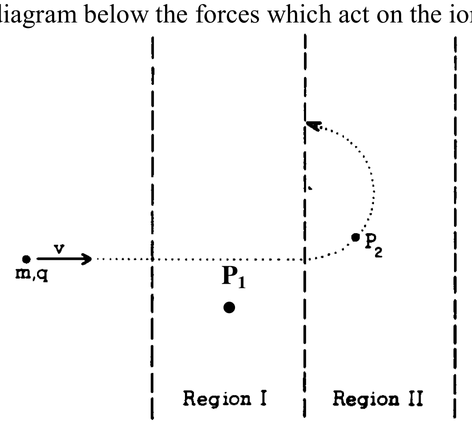
1976E3. An ion of mass m and charge of known magnitude q is observed to move in a straight line through a region of space in which a uniform magnetic field **B** points out of the paper and a uniform electric field **E** points toward the top edge of the paper, as shown in region I above. The particle travels into region II in which the same magnetic field is present, but the electric field is zero. In region II the ion moves in a circular path of radius R as shown.

a. Indicate on the diagram below the direction of the force on the ion at point P_2, in region II.



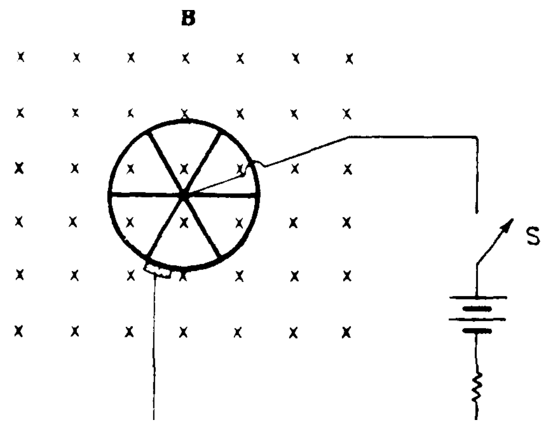
b. Is the ion positively or negatively charged? Explain clearly the reasoning on which you base your conclusion.

c. Indicate and label on the diagram below the forces which act on the ion at point P_1 in region I.



d. Find an expression for the ion's speed v at point P_1 in terms of E and B.

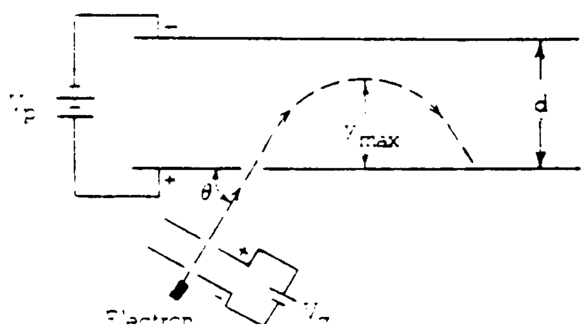
e. Starting with Newton's law, derive an expression for the mass m of the ion in terms of B, E, q, and R.



1977E3. A wheel with six spokes is positioned perpendicular to a uniform magnetic field B of magnitude 0.5 tesla (weber per square meter). The field is directed into the plane of the paper and is present over the entire region of the wheel as shown above. When the switch S is closed, there is an initial current of 6 amperes between the axle and the rim, and the wheel begins to rotate. The resistance of the spokes and the rim may be neglected.

a. What is the direction of rotation of the wheel? Explain.

b. The radius of the wheel is 0.2 meters. Calculate the initial torque on the wheel.



1978E1. Electrons are accelerated from rest in an electron gun between two plates that have a voltage V_g across them. The electrons then move into the region between two other parallel plates of separation d that have voltage V_p across them. The electrons are projected into this region at an angle θ to the plates as shown above. Assume that the entire apparatus is in vacuum and that $V_p > V_g$. Display all results in terms that include d, V_g, V_p, θ, e (the magnitude of the electron charge), and m_o (the electron mass).

a. Develop an equation for the speed v_e with which the electrons leave the electron gun.

b. Develop an equation for the maximum distance y_{max} that the electrons travel above the lower plate.

Suppose that a magnetic field directed into the plane of the paper is introduced in the region between the upper plates

c. How will the speed with which the electrons strike the lower plate be affected? Explain.

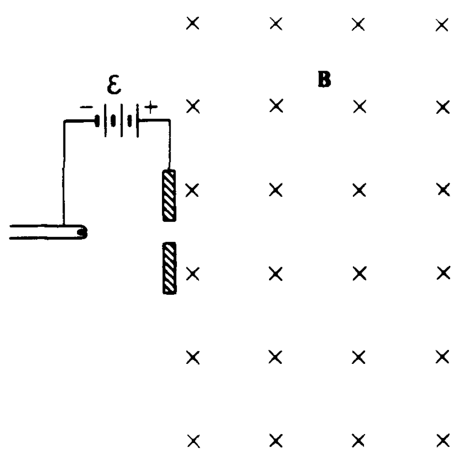
d. Sketch on the diagram a trajectory that an electron might follow with the magnetic field present. Account qualitatively for the difference between the new and old trajectory.

1979E3. A uniform magnetic field exists in a region of space. Two experiments were done to discover the direction of the field and the following results were obtained.

A proton moving to the right with instantaneous velocity $\mathbf{v_1}$ experienced a force $\mathbf{F_1}$ directed into the page, as shown above.

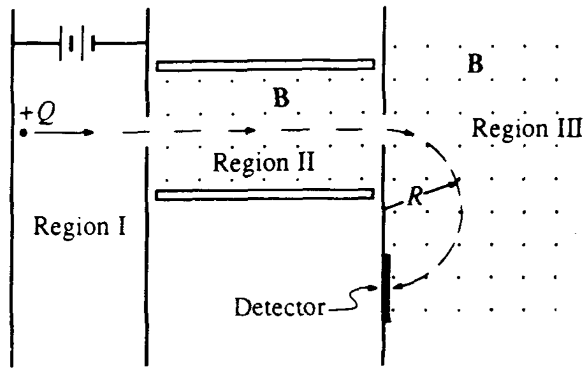
A proton moving out of the page with instantaneous velocity $\mathbf{v_2}$ experienced a force $\mathbf{F_2}$ in the plane of the page as shown above.

a. State the direction of the magnetic field and show that your choice accounts for the directions of the forces in both experiments.
b. In which experiment did the proton describe a circular orbit? Explain your choice and determine the radius of the circular orbit in terms of the given force and velocity for the proton and the proton mass m.
c. Describe qualitatively the motion of the proton in the other experiment.



1984E1. An electron from a hot filament in a cathode ray tube is accelerated through a potential difference $\mathcal{E}$. It then passes into a region of uniform magnetic field B. directed into the page as shown above. The mass of the electron is *m* and the charge has magnitude *e*.

a. Find the potential difference ε necessary to give the electron a speed v as it enters the magnetic field.
b. On the diagram above, sketch the path of the electron in the magnetic field.
c. In terms of mass m, speed v, charge *e,* and field strength B, develop an expression for r, the radius of the circular path of the electron.
d. An electric field E is now established in the same region as the magnetic field, so that the electron passes through the region undeflected.
   i. Determine the magnitude of E.
   ii. Indicate the direction of E on the diagram above.

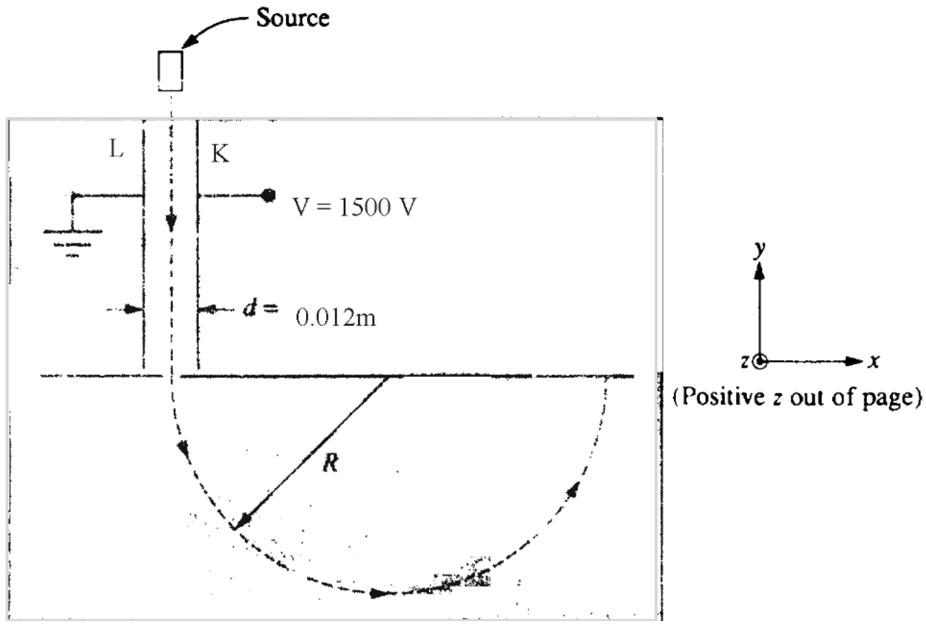


1990E2. In the mass spectrometer shown above, particles having a net charge +Q are accelerated from rest through a potential difference in Region I. They then move in a straight line through Region II, which contains a magnetic field **B** and an electric field **E**. Finally, the particles enter Region III, which contains only a magnetic field **B**, and move in a semicircular path of radius R before striking the detector. The magnetic fields in Regions II and III are uniform, have the same magnitude **B**, and are directed out of the page as shown.

a. In the figure above. indicate the direction of the electric field necessary for the particles to move in a straight line through Region II.

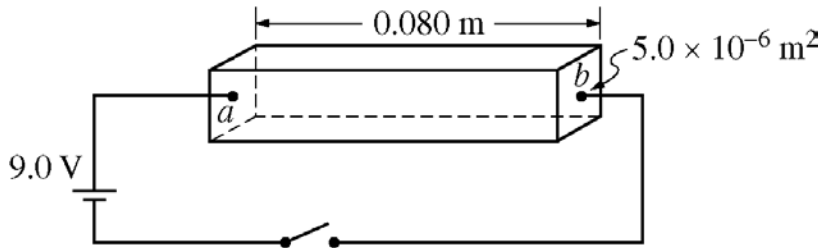
In terms of any or all the quantities Q, B, E, and R, determine expressions for

b. the speed v of the charged particles as they enter Region III;
c. the mass m of the charged particles;
d. the accelerating potential V in Region I;
e. the acceleration a of the particles in Region III;
f. the time required for the particles to move along the semicircular path in Region III.



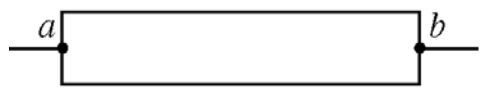
1993E3. A mass spectrometer, constructed as shown in the diagram above, is to be used for determining the mass of singly ionized positively charged ions. There is a uniform magnetic field B = 0.20 tesla perpendicular to the page in the shaded region of the diagram. A potential difference V = 1,500 volts is applied across the parallel plates L and K, which are separated by a distance d = 0.012 meter and which act as a velocity selector.

a. In which direction, relative to the coordinate system shown above on the right, should the magnetic field point in order for positive ions to move along the path shown by the dashed line in the diagram above?
b. Should plate K have a positive or negative voltage polarity with respect to plate L?
c. Calculate the magnitude of the electric field between the plates.
d. Calculate the speed of a particle that can pass between the parallel plates without being deflected.
e. Calculate the mass of a hypothetical singly charged ion that travels in a semicircle of radius R = 0.50 meter.
f. A doubly ionized positive ion of the same mass and velocity as the singly charged ion enters the mass spectrometer. What is the radius of its path?



2009E2. A 9.0 V battery is connected to a rectangular bar of length 0.080 m, uniform cross-sectional area $5.0 \times 10^{-6} m^2$, and resistivity $4.5 \times 10^{-4}\ \Omega$-m, as shown above. Electrons are the sole charge carriers in the bar. The wires have negligible resistance. The switch in the circuit is closed at time $t = 0$.

(a) Calculate the power delivered to the circuit by the battery.
(b) On the diagram below, indicate the direction of the electric field in the bar.

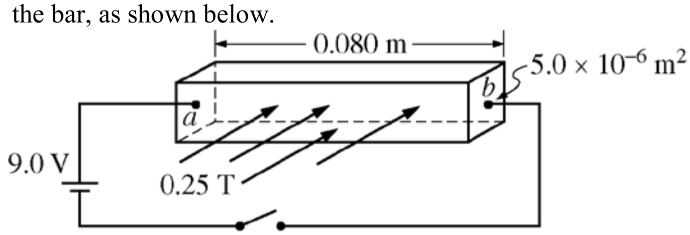


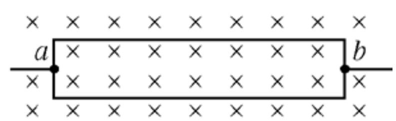
Side View

Explain your answer.

(c) Calculate the strength of the electric field in the bar.

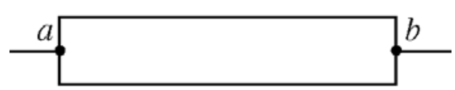
A uniform magnetic field of magnitude 0.25 T perpendicular to the bar is added to the region around the bar, as shown below.





Side View

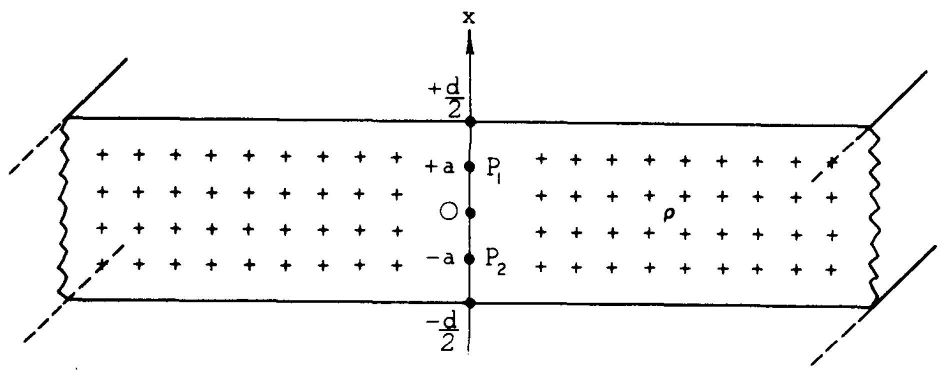
(d) Calculate the magnetic force on the bar.
(e) The electrons moving through the bar are initially deflected by the external magnetic field. On the diagram below, indicate the direction of the additional electric field that is created in the bar by the deflected electrons.



Side View

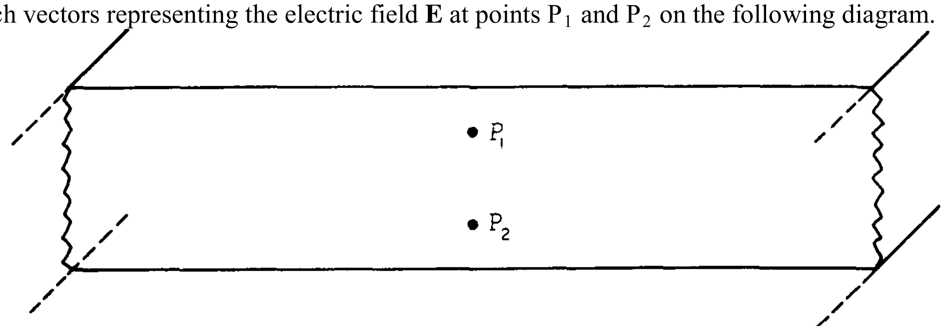
(f) The electrons eventually experience no deflection and move through the bar at an average speed of 3.5 x 10^{-3} m/s. Calculate the strength of the additional electric field indicated in part (e).

SECTION B – Biot Savart and Ampere's Law

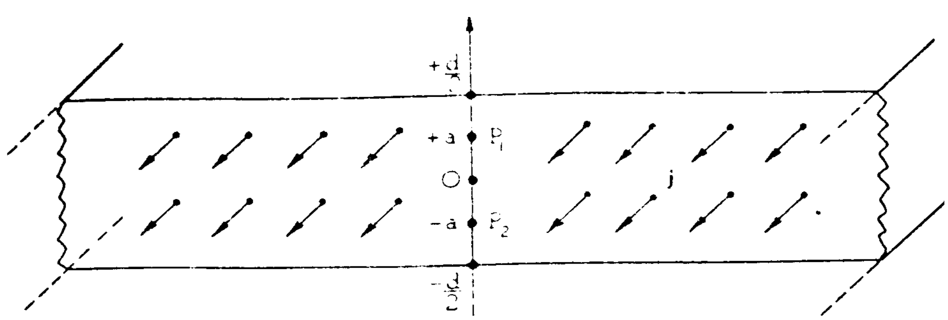


1979E2. A slab of infinite length and infinite width has a thickness d. Point P_1 is a point inside the slab at $x = a$ and point P_2 is a point inside the slab at $x = -a$. For parts (a) and (b) consider the slab to be nonconducting with uniform charge per unit volume ρ as shown.

a. Sketch vectors representing the electric field **E** at points P_1 and P_2 on the following diagram.

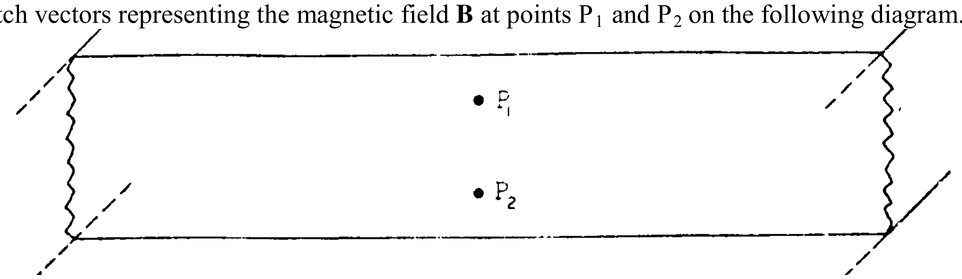


b. Use Gauss's law and symmetry arguments to determine the magnitude of E at point P_1.



For parts (c) and (d), consider the slab to be conducting and uncharged but with a uniform current density **j** directed out of the page as shown below.

c. Sketch vectors representing the magnetic field **B** at points P_1 and P_2 on the following diagram.



d. Use Ampere's law and symmetry arguments to determine the magnitude of **B** at point P_1.

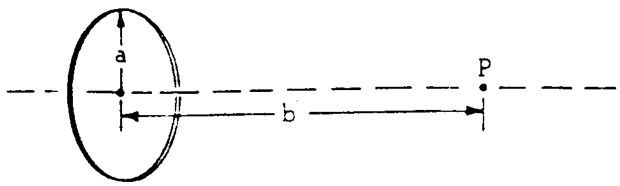


Figure I

1981E2. A ring of radius a has a total charge +Q distributed uniformly around its circumference. As shown in Figure I, the point P is on the axis of the ring at a distance b from the center of the ring.

a. On Figure I above, show the direction of the electric field at point P.

b. Determine the magnitude of the electric field intensity at point P.

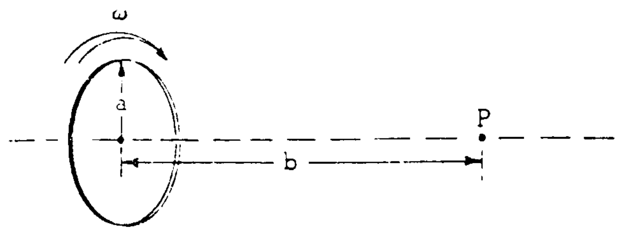


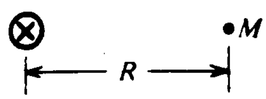
Figure II

As shown in Figure II, the ring is now rotated about its axis at a uniform angular velocity ω in a clockwise direction as viewed from point P. The charge moves with the ring.

c. Determine the current of this moving charge.

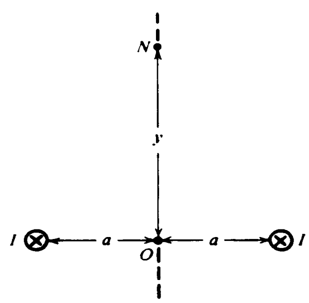
d. on Figure II above, draw the direction of the magnetic field at point P.

e. Determine the magnitude B of the magnetic field at point P.

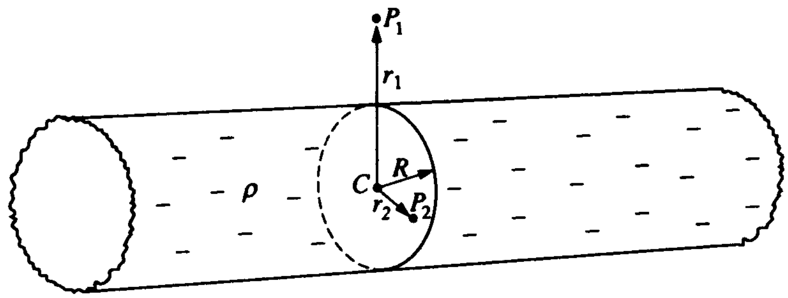


1983E3.

a. A long straight wire carries current I into the plane of the page as shown above. Using Ampere's law, develop an expression for the magnetic field intensity at a point M that is a distance R from the center of the wire. On the diagram above indicate your path of integration and indicate the direction of the field at point M.

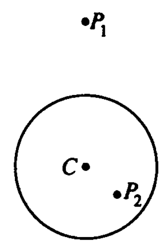


b. Two long parallel wires that are a distance 2a apart carry equal currents I into the plane of the page as shown above.
   i. Determine the resultant magnetic field intensity at the point O midway between the wires.
   ii. Develop an expression for the resultant magnetic field intensity at the point N. which is a vertical distance of y above point O. On the diagram above indicate the direction of the resultant magnetic field at point N.

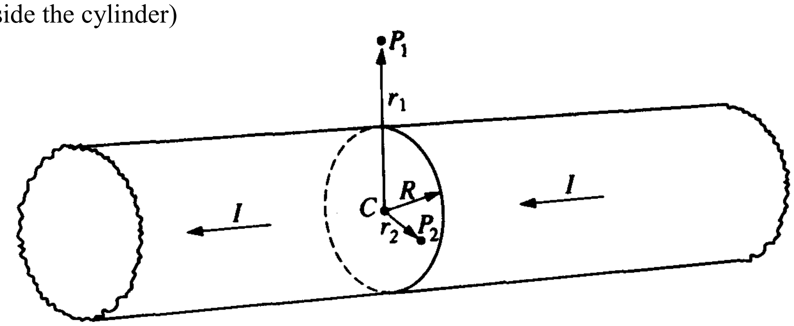


1993E1. The solid nonconducting cylinder of radius R shown above is very long. It contains a negative charge evenly distributed throughout the cylinder, with volume charge density ρ. Point P_1 is outside the cylinder at a distance r_1 from its center C and point P_2 is inside the cylinder at a distance r_2 from its center C. Both points are in the same plane, which is perpendicular to the axis of the cylinder.

a. On the following cross-sectional diagram, draw vectors to indicate the directions of the electric field at points P_1 and P_2.

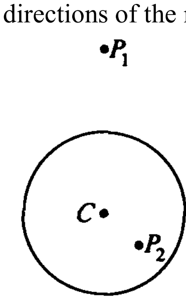


b. Using Gauss's law, derive expressions for the magnitude of the electric field E in terms of r, R. ρ, and fundamental constants for the following two cases.
  i. $r > R$ (outside the cylinder)
  ii. $r < R$ (inside the cylinder)

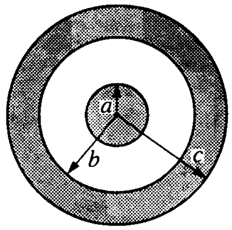


Another cylinder of the same dimensions, but made of conducting material, carries a total current I parallel to the length of the cylinder, as shown in the diagram above. The current density is uniform throughout the cross-sectional area of the cylinder. Points P_1 and P_2 are in the same positions with respect to the cylinder as they were for the nonconducting cylinder.

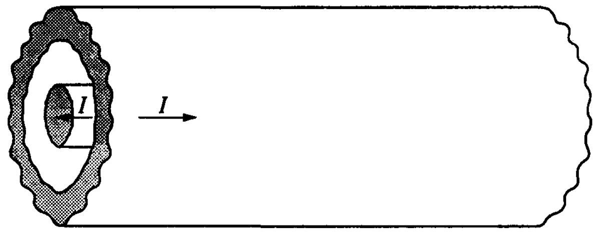
c. On the following cross-sectional diagram in which the current is out of the plane of the page (toward the reader), draw vectors to indicate the directions of the magnetic field at points P_1 and P_2.



d. Use Ampere's law to derive an expression for the magnetic field B inside the cylinder in terms of r, R, I, and fundamental constants.



Cross Section



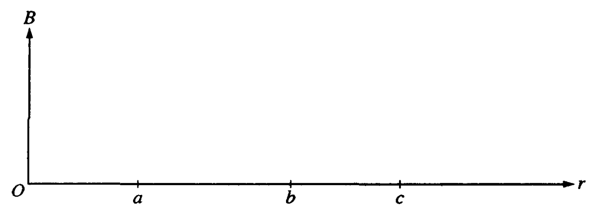
Coaxial Cable

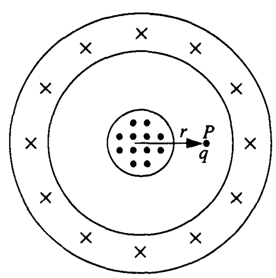
1994E3. A long coaxial cable, a section of which is shown above, consists of a solid cylindrical conductor of radius a, surrounded by a hollow coaxial conductor of inner radius *b* and outer radius c. The two conductors each carry a uniformly distributed current I, but in opposite directions. The current is to the right in the outer cylinder and to the left in the inner cylinder. Assume $\mu = \mu_o$ for all materials in this problem.

a. Use Ampere's law to determine the magnitude of the magnetic field at a distance r from the axis of the cable in each of the following cases.
   i. $0 < r < a$ ii. $a < r < b$

b. What is the magnitude of the magnetic field at a distance $r = 2c$ from the axis of the cable?

c. On the axes below, sketch the graph of the magnitude of the magnetic field B as a function of r, for all values of r. You should estimate and draw a reasonable graph for the field between b and c rather than attempting to determine an exact expression for the field in this region.



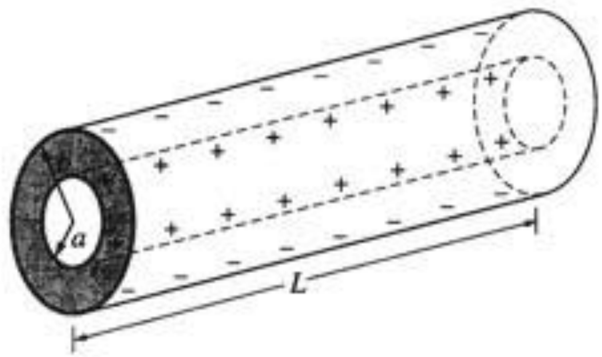


Cross Section

The coaxial cable continues to carry currents I as previously described. In the cross section above, current is directed out of the page toward the reader in the inner cylinder and into the page in the outer cylinder. Point P is located between the inner and outer cylinders, a distance r from the center. A small positive charge q is introduced into the space between the conductors so that when it is at point P its velocity v is directed out of the page, perpendicular to it, and parallel to the axis of the cable.

d. i. Determine the magnitude of the force on the charge q at point P in terms of the given quantities.
   ii. Draw an arrow on the diagram at P to indicate the direction of the force.

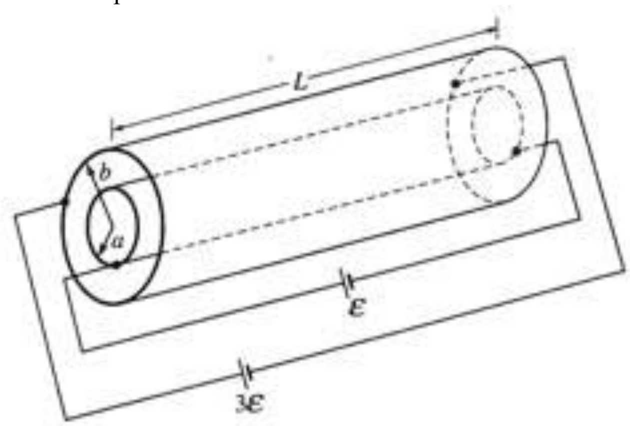
e. If the current in the outer cylinder were reversed so that it is directed out of the page, how would your answers to (d) change, if at all?



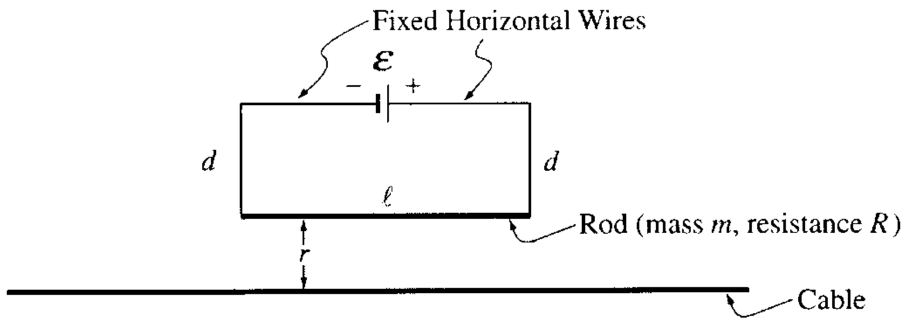
2000E3. A capacitor consists of two conducting, coaxial, cylindrical shells of radius *a* and *b,* respectively, and length $L >> b$. The space between the cylinders is filled with oil that has a dielectric constant x. Initially both cylinders are uncharged, but then a battery is used to charge the capacitor, leaving a charge +Q on the inner cylinder and -Q on the outer cylinder, as shown above. Let *r* be the radial distance from the axis of the capacitor.

a. Using Gauss's law, determine the electric field midway along the length of the cylinder for the following values of *r,* in terms of the given quantities and fundamental constants. Assume end effects are negligible.
   i. $a < r < b$
   ii. $b < r << L$

b. Determine the following in terms of the given quantities and fundamental constants.
   i. The potential difference across the capacitor
   ii. The capacitance of this capacitor



c. Now the capacitor is discharged and the oil is drained from it. As shown above, a battery of emf ε *is* connected to opposite ends of the inner cylinder and a battery of emf *3*ε is connected to opposite ends of the outer cylinder. Each cylinder has resistance R. Assume that end effects and the contributions to the magnetic field from the wires are negligible. Using Ampere's law, determine the magnitude B of the magnetic field midway along the length of the cylinders due to the current in the cylinders for the following values of *r*.
   i. $a < r < b$
   ii. $b < r << L$



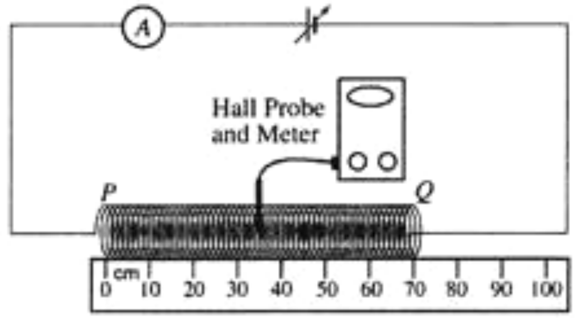
2001E3. The circuit shown above consists of a battery of emf $\mathcal{E}$ in series with a rod of length l, mass m, and resistance R. The rod is suspended by vertical connecting wires of length d, and the horizontal wires that connect to the battery are fixed. All these wires have negligible mass and resistance. The rod is a distance r above a conducting cable. The cable is very long and is located directly below and parallel to the rod. Earth's gravitational pull is toward the bottom of the page. Express all algebraic answers in terms of the given quantities and fundamental constants.

a. What is the magnitude and direction of the current I in the rod?

b. In which direction must there be a current in the cable to exert an upward force on the rod? Justify your answer.

c. With the proper current in the cable, the rod can be lifted up such that there is no tension in the connecting wires. Determine the minimum current I_C in the cable that satisfies this situation.

d. Determine the magnitude of the magnetic flux through the circuit due to the minimum current I_C determined in part c.



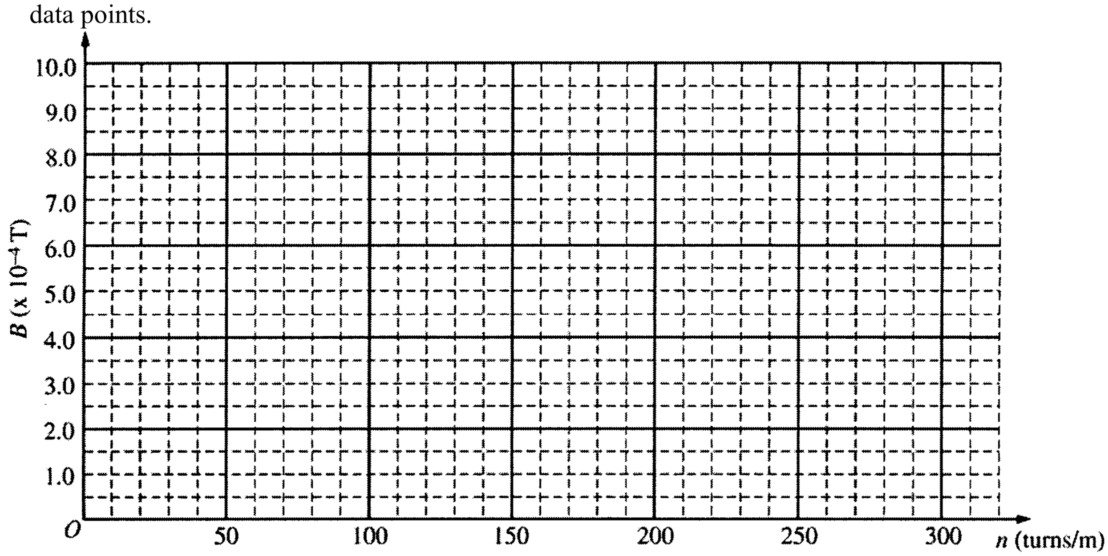
2005E3. A student performs an experiment to measure the magnetic field along the axis of the long, 100-turn solenoid *PQ* shown above. She connects ends *P* and *Q* of the solenoid to a variable power supply and an ammeter as shown. End *P* of the solenoid is taped at the 0 cm mark of a meter stick. The solenoid can be stretched so that the position of end *Q* can be varied. The student then positions a Hall probe* in the center of the solenoid to measure the magnetic field along its axis. She measures the field for a fixed current of 3.0 A and various positions of the end *Q*. The data she obtains are shown below.

* A Hall Probe is a device used to measure the magnetic field at a point.

Trial	Position of End *Q* (cm)	Measured Magnetic Field (T) (directed from *P* to *Q*)	*n* (turns/m)
1	40	9.70×10^{-4}	
2	50	7.70×10^{-4}	
3	60	6.80×10^{-4}	
4	80	4.90×10^{-4}	
5	100	4.00×10^{-4}	

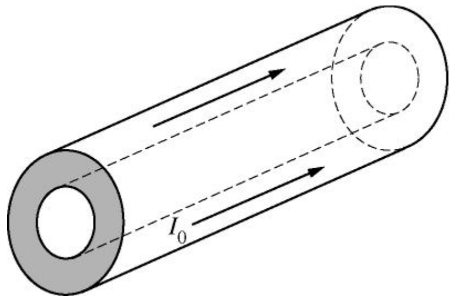
a. Complete the last column of the table above by calculating the number of turns per meter.

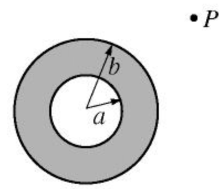
b. On the axes below, plot the measured magnetic field B versus *n*. Draw a best-fit straight line for the data points.



c. From the graph, obtain the value of μ_0, the magnetic permeability of vacuum.

d. Using the theoretical value of $\mu_0 = 4\pi \times 10^{-7}$ T m/A, determine the percent error in the experimental value of μ_0 computed in part (c).





Cross-sectional View
(current into page)

2011E3. A section of a long conducting cylinder with inner radius a and outer radius b carries a current I_0 that has a uniform current density, as shown in the figure above.

(a) Using Ampère's law, derive an expression for the magnitude of the magnetic field in the following regions as a function of the distance r from the central axis.

i. $r < a$

ii. $a < r < b$

iii. $r = 2b$

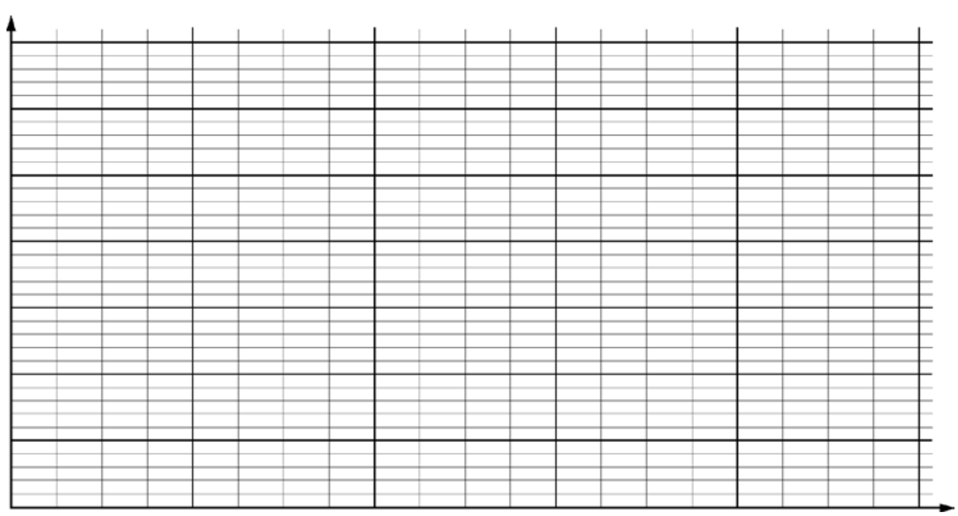
(b) On the cross-sectional view in the diagram above, indicate the direction of the field at point P, which is at a distance $r = 2b$ from the axis of the cylinder.

(c) An electron is at rest at point P. Describe any electromagnetic forces acting on the electron. Justify your answer.

Now consider a long, <u>solid</u> conducting cylinder of radius b carrying a current I_0 . The magnitude of the magnetic field inside this cylinder as a function of r is given by $B = \mu_0 I_0 r/2\pi b^2$. An experiment is conducted using a particular solid cylinder of radius 0.010 m carrying a current of 25 A. The magnetic field inside the cylinder is measured as a function of r, and the data is tabulated below.

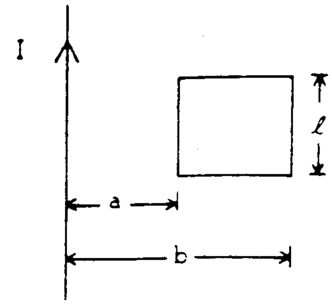
Distance r (m)	0.002	0.004	0.006	0.008	0.010
Magnetic Field B (T)	1.2×10^{-4}	2.7×10^{-4}	3.6×10^{-4}	4.7×10^{-4}	6.4×10^{-4}

(d) i. On the graph below, plot the data points for the magnetic field B as a function of the distance r, and label the scale on both axes. Draw a straight line that best represents the data.



ii. Use the slope of your line to estimate a value of the permeability μ_0 .

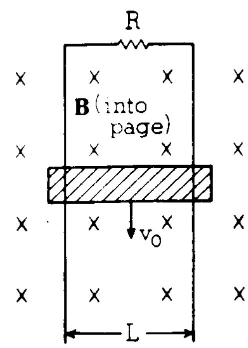
SECTION C – Induction and Inductance



1975E3. A long straight conductor lies in the plane of a rectangular loop of wire as shown above. The total resistance of the loop is R. The current in the long straight conductor increases at a constant rate dI/dt.

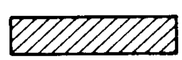
a. Indicate on the diagram the direction of the induced current in the loop and explain your reasoning.

b. Determine the magnitude of the current assuming the self-inductance of the loop may be neglected.



1976E2. A conducting bar of mass M slides without friction down two vertical conducting rails which are separated by a distance L and are joined at the top through an unknown resistance R. The bar maintains electrical contact with the rails at all times. There is a uniform magnetic field B, directed into the page as shown above. The bar is observed to fall with a constant terminal speed v_0.

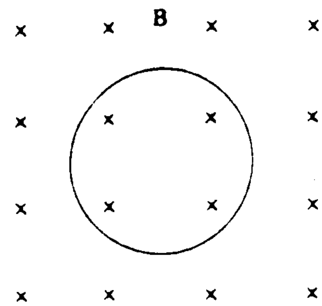
a. On the diagram below, draw and label all the forces acting on the bar.



b. Determine the magnitude of the induced current I in the bar as it falls with constant speed v_0 in terms of B, L, g, v_0, and M.

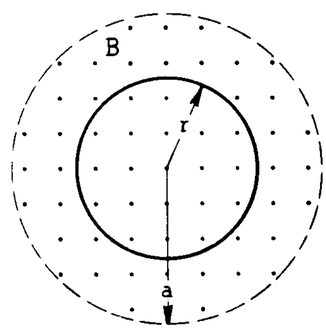
c. Determine the voltage induced in the bar in terms of B, L, g, v_0, and M.

d. Determine the resistance R in terms of B, L, g, v_0, and M.



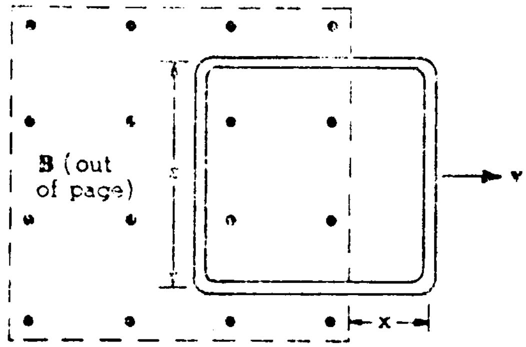
1978E2. A circular loop of wire of area A and electrical resistance R is placed in a spatially uniform magnetic field B directed into the page and perpendicular to the plane of the loop as shown above. The magnetic field is gradually reduced from an initial value of B_o, in such a way that the magnetic field strength as a function of time is $B(t) = B_o e^{-\alpha t}$.

a. Indicate on the diagram the direction of the induced current. Applying the fundamental relation for electromagnetic induction, explain your choice.
b. Do the electromagnetic forces on this current tend to make the loop expand or contract? Explain.
c. Determine an expression, in terms of B_o, A, and R, that describes the total quantity of charge that flows past a point in the loop during the time the magnetic field is reduced from B_o to zero.
d. Determine an expression for the amount of energy dissipated as heat in the loop, in terms of B_o, A, R, and α, during the time the magnetic field is reduced from B_o to zero.



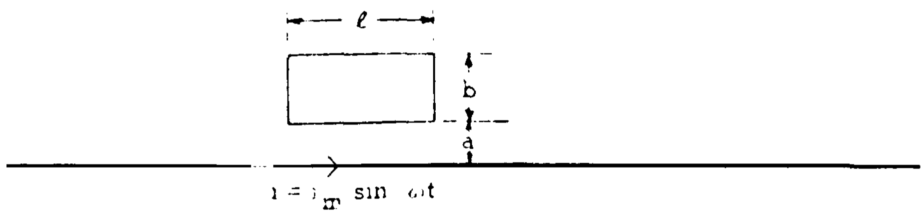
1980E3. A spatially uniform magnetic field directed out of the page is confined to a cylindrical region of space of radius a as shown above. The strength of the magnetic field increases at a constant rate such that
$B = B_o + Ct$, where B_o and C are constants and t is time. A circular conducting loop of radius r and resistance R is placed perpendicular to the magnetic field.

a. Indicate on the diagram above the direction of the induced current in the loop. Explain your choice.
b. Derive an expression for the induced current in the loop.
c. Derive an expression for the magnitude of the induced electric field at any radius $r < a$.
d. Derive an expression for the magnitude of the induced electric field at any radius $r > a$.



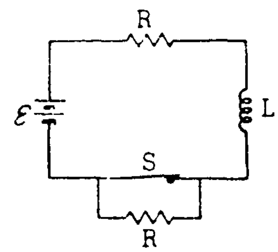
1981E3. A square loop of wire of side s and resistance R is pulled at constant velocity **v** out of a uniform magnetic field of intensity B. The plane of the loop is always perpendicular to the magnetic field. After the leading edge of the loop has passed the edge of the B field as shown in the figure above, there is an induced current in the loop.

a. On the figure above, indicate the direction of this induced current.
b. Using Faraday's law of induction, develop an expression for the induced emf ε in the loop.
c. Determine the induced current I in the loop.
d. Determine the power required to keep the loop moving at constant velocity.



1982E2. As shown above a rectangular loop is located next to a long straight wire carrying a current
$i = i_m \sin\omega t$
The wire and the loop are in the plane of the page and fixed in space

a. Using Ampere's law, show that the magnetic c field intensity at a distance r from the wire is $B = \mu_o i/2\pi r$, with μ_o being the permeability of free space.
b. Find the magnetic flux Φ_B through the loop at time t.
c. The current i in the long wire is in the direction shown above from $t = 0$ to $t = \pi/\omega$.
i. indicate on the diagram above the direction of the resulting current induced in the loop at time $t = \pi/\omega$
ii. Determine the emf that is induced in the loop at time $t = \pi/\omega$.



1982E3. When the switch S in the circuit shown above is closed, an inductance L is in series with a resistance R and battery of emf $\mathcal{E}$.

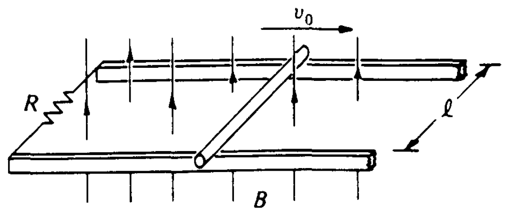
a. Determine the current i in the circuit after the switch S has been closed for a very long time.
After being closed for a very long time, the switch S is opened at time t = 0.

b. Determine the current i_B in the circuit after the switch has been open for a very long time.

c. On the axes below, sketch a graph of the current as a function of time t for $t \geq 0$ and indicate the values of the currents i_A and i_B on the vertical axis

d. By relating potential difference and emfs around the circuit, write the differential equation that can be used to determine the current as a function of time.

e. Write the equation for the current as a function of time for all time $t \geq 0$.



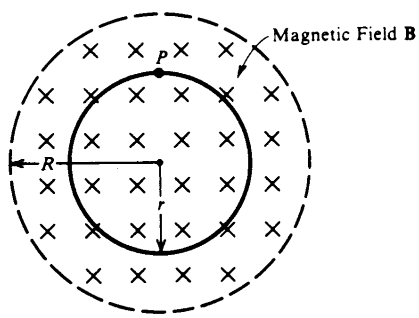
1984E3. Two horizontal conducting rails are separated by a distance l as shown above. The rails are connected at one end by a resistor of resistance R. A conducting rod of mass m can slide without friction along the rails. The rails and the rod have negligible resistance. A uniform magnetic field of magnitude B is perpendicular to the plane of the rails as shown. The rod is given a push to the right and then allowed to coast. At time t = 0 (immediately after it is pushed) the rod has a speed v_o to the right.

a. Indicate on the diagram above the direction of the induced current in the resistor.
b. In terms of the quantities given, determine the magnitude of the induced current in the resistor at time t = 0
c. Indicate on the diagram above the direction of the force on the rod.
d. In terms of the quantities given, determine the magnitude of the force acting on the rod at time t = 0.

If the rod is allowed to continue to coast, its speed as a function of time will be as follows.

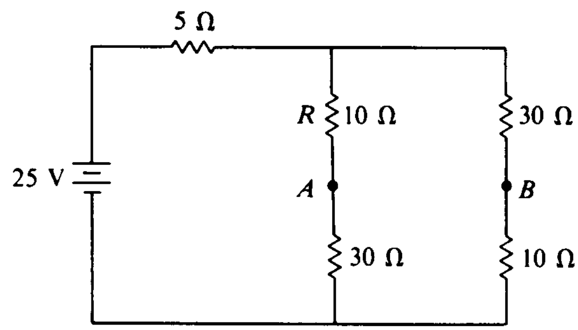
$$v = v_o e^{-(B^2 l^2 t/Rm)}$$

e. In terms of the quantities given, determine the power developed in the resistor as a function of time t.
f. Show that the total energy produced in the resistor is equal to the initial kinetic energy of the bar.



1985E3. A spatially uniform magnetic field B. perpendicular to the plane of the page, exists in a circular region of radius R = 0.75 meter as shown above. A single wire loop of radius r = 0.5 meter is placed concentrically in the magnetic field and in the plane of the page. The magnetic field increases into the page at a constant rate of 60 teslas per second.

a. Determine the induced emf in the loop.
b. Determine the magnitude and direction of the induced electric field at point P and indicate its direction on the diagram above.
The wire loop is replaced by an evacuated doughnut-shaped glass tube, within which a single electron orbits at a constant radius r = 0.5 meter when the spatially uniform magnetic field is constant at 10^{-4} tesla.
c. Determine the speed of the electron in this orbit.
d. The magnetic field is now made to increase at a constant rate of 60 teslas per second as in parts (a) and (b) above. Determine the tangential acceleration of the electron at the instant the field begins to increase.



1986E2. Five resistors are connected as shown above to a 25-volt source of emf with zero internal resistance.

a. Determine the current in the resistor labeled *R*.

A 10-microfarad capacitor is connected between points A and *B*. The currents in the circuit and the charge on the capacitor soon reach constant values. Determine the constant value for each of the following.

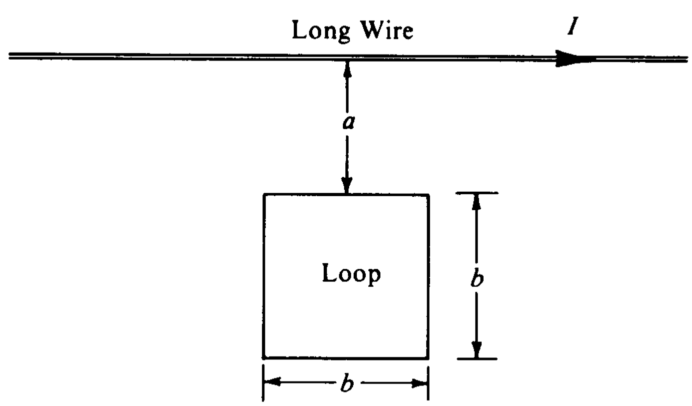
b. The current in the resistor *R*

c. The charge on the capacitor

The capacitor is now replaced by a 2.0-henry inductor with zero resistance. The currents in the circuit again reach constant values. Determine the constant value for each of the following.

d. The current in the resistor *R*

e. The current in the inductor



1986E3. A long wire carries a current in the direction shown above. The current I varies linearly with time t as follows: I = ct, where c is a positive constant. The long wire is in the same plane as a square loop of wire of side b, as shown in the diagram. The side of the loop nearest the long wire is parallel to it and a distance a from it. The loop has a resistance R and is fixed in space.

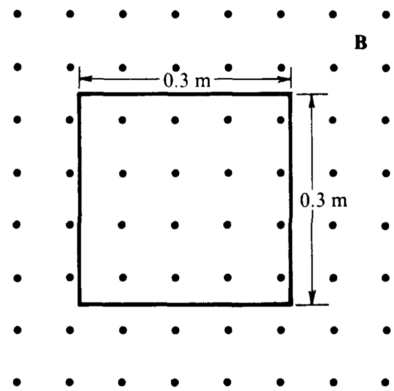
a. Determine the magnetic field *B* at a distance r from the long wire as a function of time.

b. Indicate on the diagram the direction of the induced current in the loop.

c. Determine the induced current in the loop.

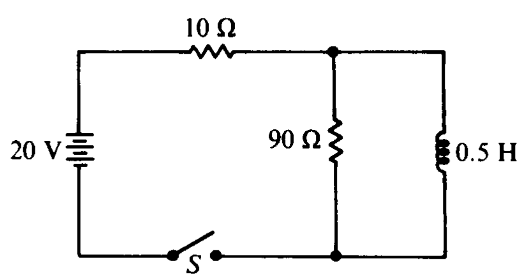
d. State whether the magnetic force on the loop is toward or away from the wire.

e. Determine the magnitude of the magnetic force on the loop as a function of time.



1987E2. A square wire loop of resistance 6 ohms and side of length 0.3 meter lies in the plane of the page, as shown above. The loop is in a magnetic field B that is directed out of the page. At time t = 0, the field has a strength of 2 teslas; it then decreases according to the equation $B = 2e^{-4t}$, where B is in teslas and t is in seconds.

a. Determine an expression for the flux through the loop as a function of time t for t > 0.
b. On the diagram above, indicate the direction of the current induced in the loop for time t > 0.
c. Determine an expression for the current induced in the loop for time t > 0.
d. Determine the total energy dissipated as heat during the time from zero to infinity.



1987E3. In the circuit shown above, the switch S is initially open and all currents are zero. For the instant immediately after the switch is closed, determine each of the following.

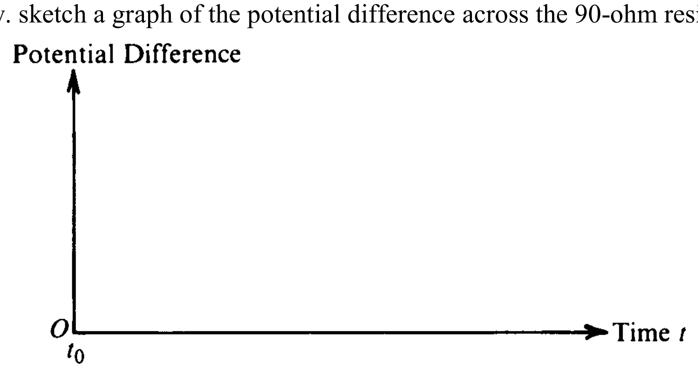
a. The potential difference across the 90-ohm resistor
b. The rate of change of current in the inductor

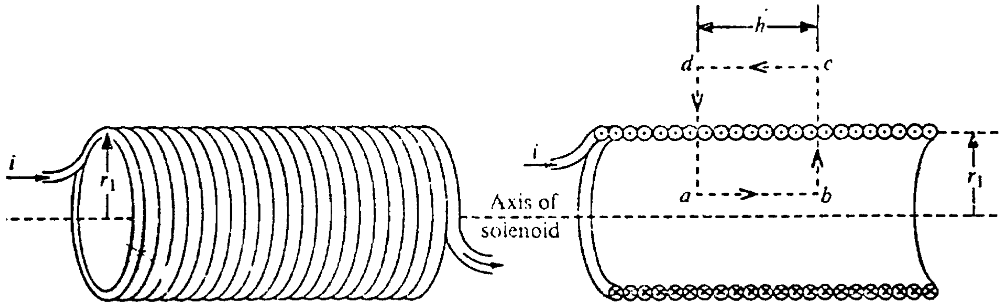
The switch has remained closed for a long time. Determine each of the following.

c. The current in the inductor
d. The energy stored in the inductor

Later, at time t_o, the switch is reopened.

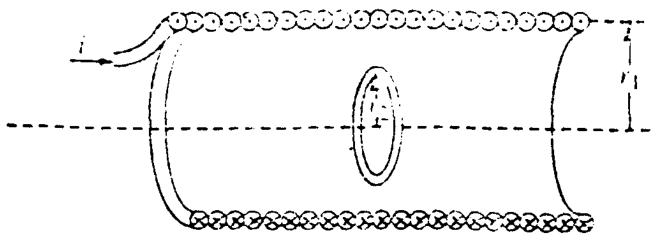
e. For the instant immediately after the switch is reopened, determine the potential difference across the 90-ohm resistor.
f. On the axes below. sketch a graph of the potential difference across the 90-ohm resistor for $t > t_o$.





1988E3. The long solenoid shown in the left-hand figure above has radius r_1 and n turns of wire per unit length, and it carries a current i. The magnetic field outside the solenoid is negligible.

a. Apply Ampere's law using the path abcda indicated in the cross section shown in the righthand figure above to derive an expression for the magnitude of the magnetic field B near the center of the solenoid

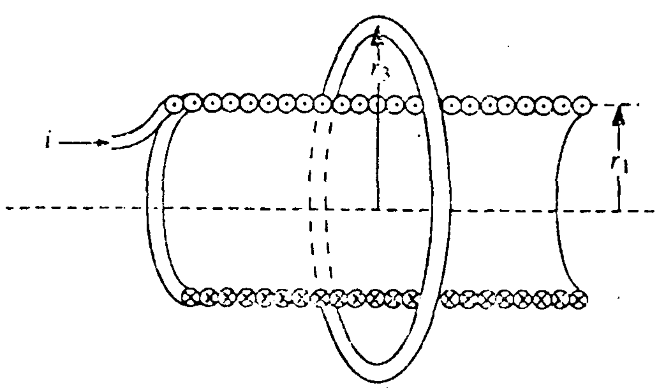


A loop of radius r_2 is then placed at the center of the solenoid, so that the plane of the loop is perpendicular to the axis of the solenoid, as shown above. The current in the solenoid is decreased at a steady rate from i to zero in time t. In terms of the given quantities and fundamental constants, determine:

b. The emf induced in the loop.

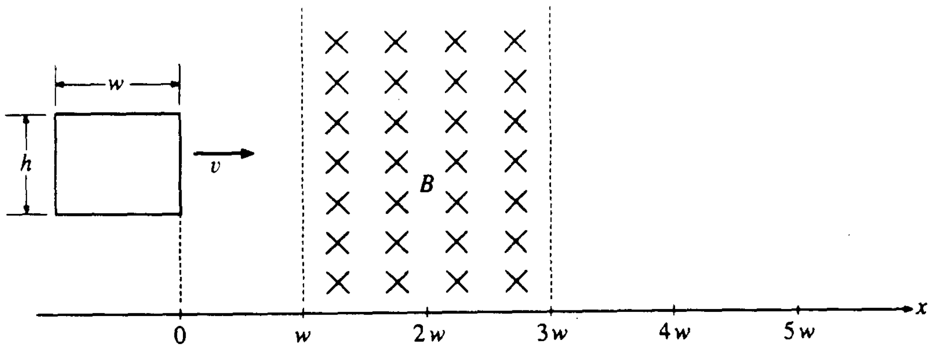
c. The magnitude of the induced electric field at a point in the loop.

The loop is now removed and another loop of radius r_3 is placed outside the solenoid, so that the plane of the loop is perpendicular to the axis of the solenoid, as shown above. The current in the solenoid is again decreased at a steady rate from i to zero in time t. In terms of the given quantities and fundamental constants, determine:



d. The emf induced in the loop.

e. The magnitude of the induced electric field at a point in the loop.

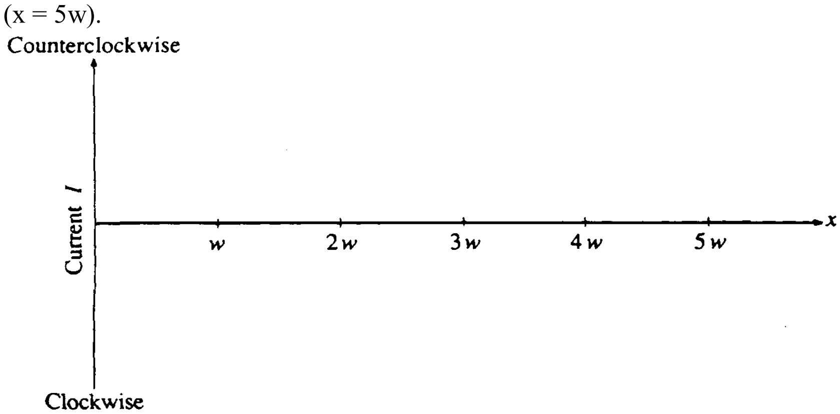


1989E2. A rectangular loop of wire of resistance R and dimensions h and w moves with a constant speed v toward and through a region containing a uniform magnetic field of strength B directed into the plane of the page. The region has a width of w as shown above.

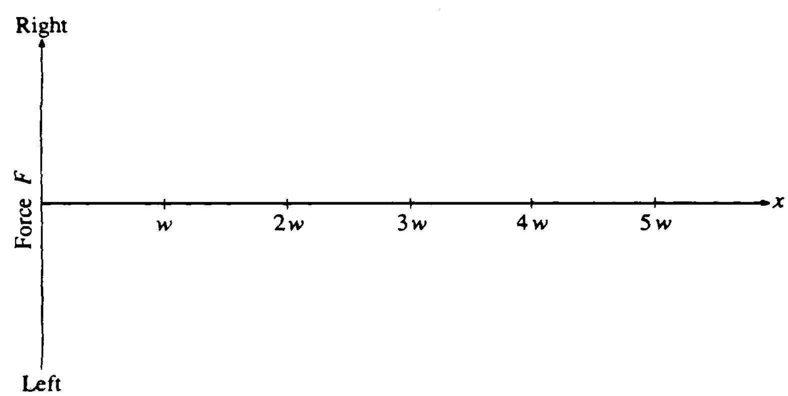
a. For the interval after the right-hand edge of the loop has entered the field but before the left-hand side of the loop has reached the field, determine each of the following in terms of B, w, h, v, and R.
   i. The magnitude of the induced current in the loop
   ii. The magnitude of the applied force required to move the loop at constant speed
b. On the axes below, plot the following as functions of position x of the right edge of the loop shown above.
   i. The induced current I in the loop
   ii. The applied force F required to keep the loop moving at constant speed

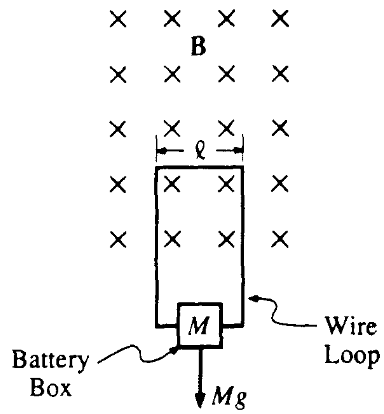
   Let counterclockwise current be positive, clockwise current be negative, forces to the right be positive, and forces to the left be negative. The graphs should begin with the loop in the position shown (x = 0) and continue until the right edge of the loop is a distance 2w to the right of the region containing the field (x = 5w).

i)



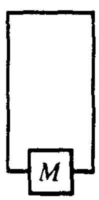
ii)





1990E3. A uniform magnetic field of magnitude B is horizontal and directed into the page in a rectangular region of space, as shown above. A light, rigid wire loop, with one side of width l, has current I. The loop is supported by the magnetic field. and hangs vertically, as shown. The wire has resistance R and supports a box that holds a battery to which the wire loop is connected. The total mass of the box and its contents is M.

a. On the following diagram that represents the rigid wire loop, indicate the direction of the current I.



The loop remains at rest. In terms of any or all of the quantities B, l, M, R, and appropriate constants, determine expressions for

b. the current I in the loop;

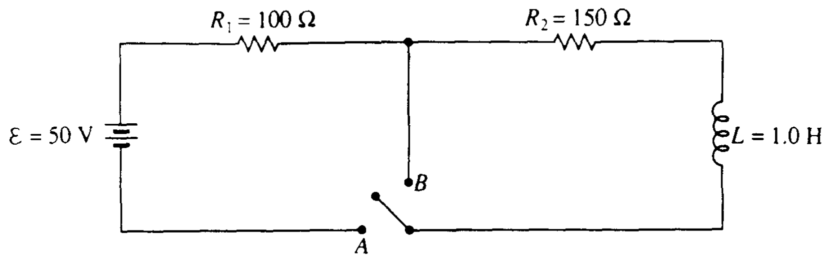
c. the emf of the battery, assuming it has negligible internal resistance.

An amount of mass Δm is removed from the box and the loop then moves upward, reaching a terminal speed v in a very short time, before the box reaches the field region. In terms of v and any or all of the original variables, determine expressions for

d. the magnitude of the induced emf;

e. the current I' in the loop under these new conditions;

f. the amount of mass Δm removed.



1991E2. In the circuit above. the switch is initially open as shown. At time t = 0, the switch is closed to position A.

a. Determine the current immediately after the switch is closed.

b. Determine the current after a long time when a steady state situation has been reached.

c. On the axes below. sketch a graph of the current *versus* time after the switch is closed.

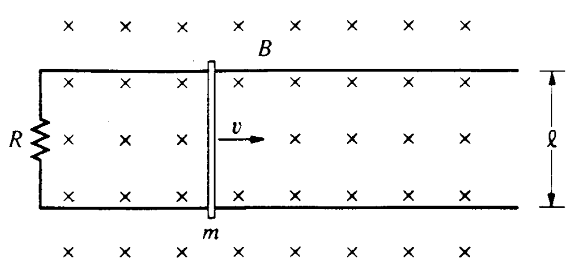
d. Determine the energy stored in the inductor L when the steady state has been reached.

Some time after the steady state situation has been reached. the switch is moved almost instantaneously from position A to position B.

e. Determine the current in the inductor immediately after the position of the switch is changed.

f. Determine the potential difference across the inductor immediately after the position of the switch is changed.

g. What happens to the energy stored in the inductor as calculated in part (d) above?



View from Above

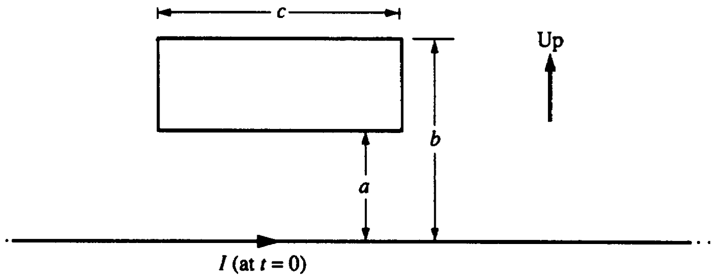
1991E3. A conducting rod is free to move on a pair of horizontal, frictionless conducting rails a distance l apart. The rails are connected at one end so a complete circuit is formed. The rod has a mass m, the resistance of the circuit is R. and there is a uniform magnetic field of magnitude B directed perpendicularly into the plane of the rails, as shown above. The rod and the rails have negligible resistance. At time t = 0, the rod has a speed v_O to the right. Determine each of the following in terms of l, m, R, B, and v_O

a. The induced voltage in the rod at t = 0

b. The magnitude and the direction of the magnetic force on the rod at t = 0

c. The speed v of the rod as a function of time t

d. The total energy dissipated by the resistor beginning at t = 0



1992E3. The rectangular wire loop shown above has length c, width (b – a), and resistance R. It is placed in the plane of the page near a long straight wire, also in the plane of the page. The long wire carries a time-dependent current $I = \alpha(1 - \beta t)$, where α and β are positive constants and t is time.

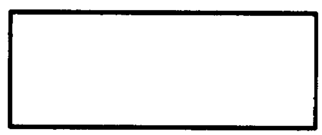
a. What is the direction of the magnetic field inside the loop due to the current I in the long wire at t=0?

b. In terms of a, b, c, α, β and fundamental constants, determine the following.
   i. An expression for the magnitude of the magnetic flux through the loop as a function of t.
   ii. The magnitude of the induced emf in the loop.

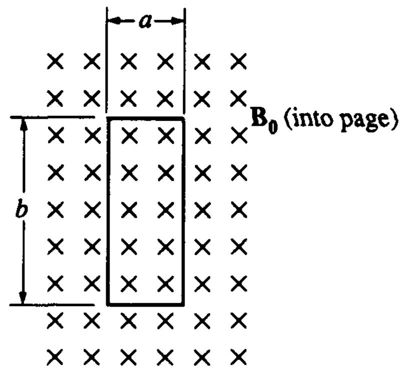
c. Show on the diagrams below the directions of the induced current in the loop for each of the following cases.

i. $\beta t < 1$

ii. $\beta t > 1$



d. What is the direction of the net force, if any, on the loop due to the induced current at t = 0 ?

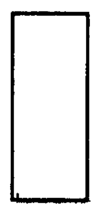


1993E2. A rectangular loop of copper wire of resistance R has width a and length b . The loop is stationary in a constant, uniform magnetic field B_o, directed into the page as shown above.

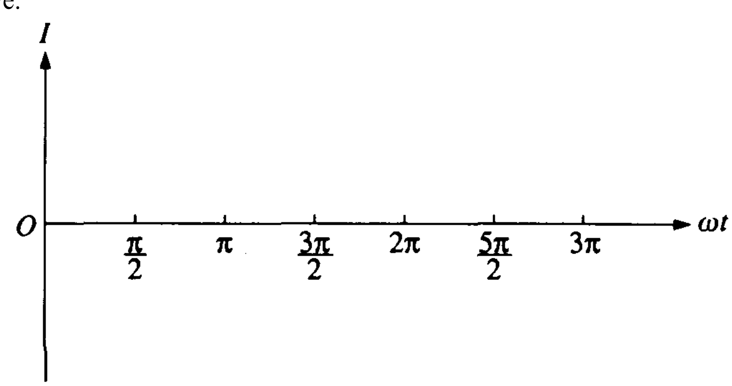
a. i. What is the net magnetic flux through the loop of wire?
ii. What is the induced emf in the loop of wire?
iii. What is the net magnetic force on the loop of wire?

Suppose instead that the uniform magnetic field varies with time t according to the relationship $B = B_o\cos(\omega t)$, where ω, and B_o are positive constants and B is positive when the field is directed into the page.

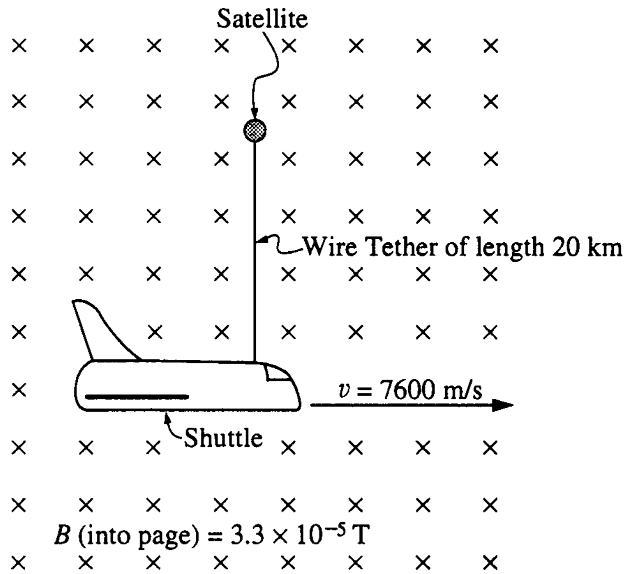
b. Indicate on the diagram below the direction of the induced current in the loop when $\omega t = \pi/2$, after the magnetic field begins to oscillate.



c. i. Derive the expression for the magnitude of the induced current in the loop as a function of time in terms of a, b, B_o, R, t, and fundamental constants.
ii. On the axes below, sketch a graph of the induced current I versus ωt, taking clockwise current to be positive.



d. State explicitly the maximum value of the current I.



1994E2. One of the space shuttle missions attempted to perform an experiment in orbit using a tethered satellite. The satellite was to be released and allowed to rise to a height of 20 kilometers above the shuttle. The tether was a 20-kilometer copper-core wire, thin and light, but extremely strong. The shuttle was in an orbit with speed 7,600 meters per second, which carried it through a region where the magnetic field of the Earth had a magnitude of 3.3×10^{-5} tesla. For your calculations, assume that the experiment was completed successfully, that the wire is perpendicular to the magnetic field, and that the field is uniform.

a. An emf is generated in the tether.
   i. Which end of the tether is negative?
   ii. Calculate the magnitude of the emf generated.

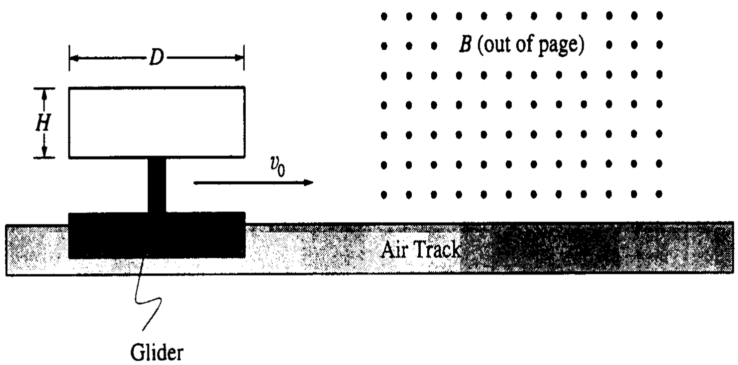
   To complete the circuit, electrons are sprayed from the object at the negative end of the tether into the ionosphere and other electrons come from the ionosphere to the object at the positive end.

b. If the resistance of the entire circuit is about 10,000 ohms, calculate the current that flows in the tether.

c. A magnetic force acts on the wire as soon as the current begins to flow.
   i. Calculate the magnitude of the force.
   ii. State the direction of the force.

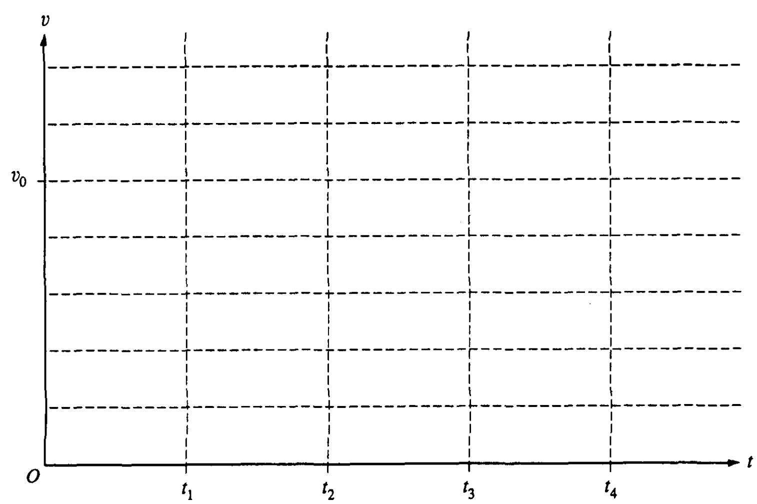
d. By how much would the shuttle's orbital energy change if the current remains constant at the value calculated in (b) for a period of 7 days in orbit?

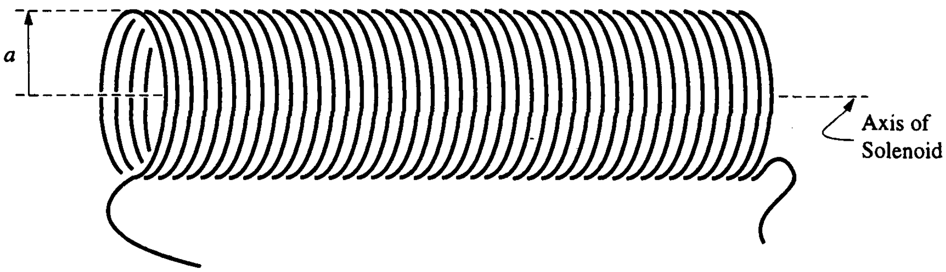
e. Imagine that the astronauts forced a current to flow the other way. What effect would that have, if any, on the orbit of the shuttle? Explain *briefly*.



1995E3. The long, narrow rectangular loop of wire shown above has vertical height H, length D, and resistance R. The loop is mounted on an insulated stand attached to a glider, which moves on a frictionless horizontal air track with an initial speed of v_o to the right. The loop and glider have a combined mass m. The loop enters a long, narrow region of uniform magnetic field B, directed out of the page toward the reader. Express your answers to the parts below in terms of B, D, H, R, m, and v_o.

a. What is the magnitude of the initial induced emf in the loop as the front end of the loop begins to enter the region containing the field?
b. What is the magnitude of the initial induced current in the loop?
c. State whether the initial induced current in the loop is clockwise or counterclockwise around the loop.
d. Derive an expression for the velocity of the glider as a function of time t for the interval after the front edge of the loop has entered the magnetic field but before the rear edge has entered the field.
e. Using the axes below, sketch qualitatively a graph of speed v versus time t for the glider. The front end of the loop enters the field at t = 0. At t_1 the back end has entered and the loop is completely inside the field. At t_2 the loop begins to come out of the field. At t_3 it is completely out of the field. Continue the graph until t_4, a short time after the loop is completely out of the field. These times may not be shown to scale on the t-axis below.



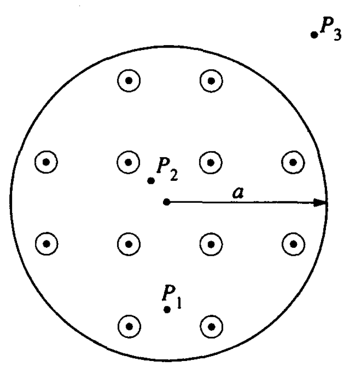


1996E3. According to Faraday's law, the induced emf E due to a changing magnetic flux ϕ_m is given by

$\mathcal{E} = \oint E \bullet dl = -d\phi_m / dt$, where E is the (induced) electric field and dl 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.

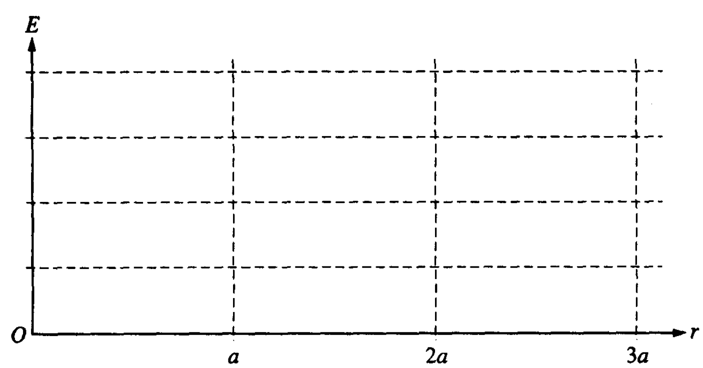
a. For r < a, where r is the distance from the axis of the solenoid, find an expression for the magnitude E of the induced electric field in terms of r and dB/dt .

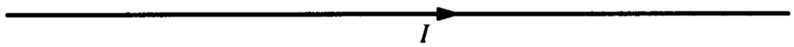
b. The figure below shows a cross section of the solenoid, with the magnetic field pointing out of the page. The electric field induced by the increasing magnetic field lies in the plane of the page. On the figure, indicate the direction of the induced electric field at the three labeled points, P_1,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



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 $0 \leq r \leq 3a$.

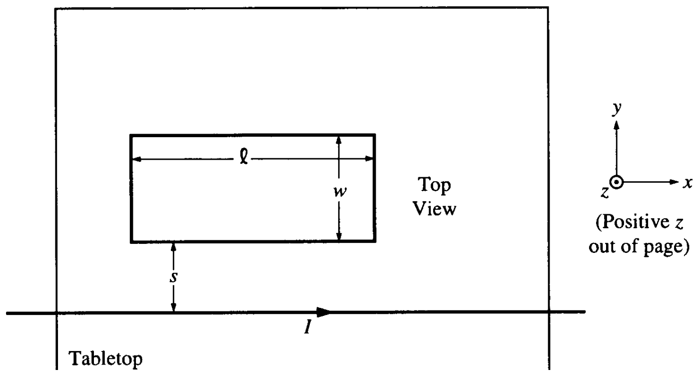




1997E3. A long, straight wire lies on a table and carries a constant current I_0, as shown above.

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

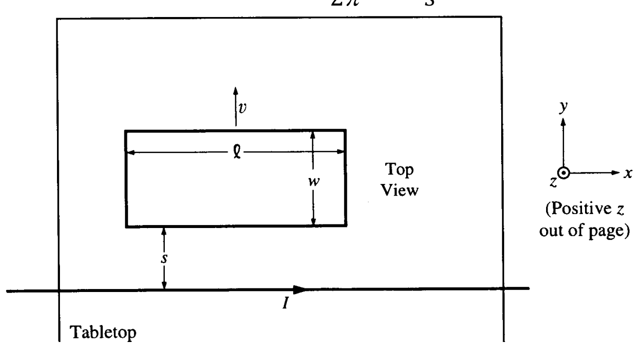
A rectangular loop of wire of length *l*, width w, and resistance R is placed on the table a distance s from the wire, as shown below.



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

c. Show that the total magnetic flux ϕ_m through the rectangular loop is

$$\frac{Il\mu_0}{2\pi}\ln\frac{s+w}{s}$$

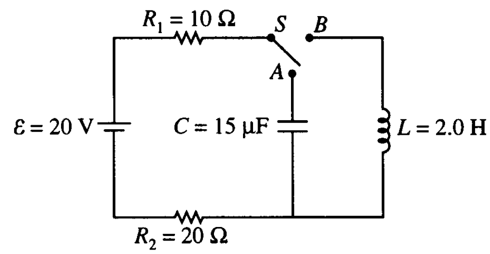


The rectangular loop is now moved along the tabletop directly away from the wire at a constant speed $v = |ds/dt|$ as shown above.

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.



1998E2. In the circuit shown above, the switch S is initially in the open position shown, and the capacitor is uncharged. A voltmeter (not shown) is used to measure the correct potential difference across resistor R_1.

a. On the circuit diagram above, draw the voltmeter with the proper connections for correctly measuring the potential difference across resistor R_1.

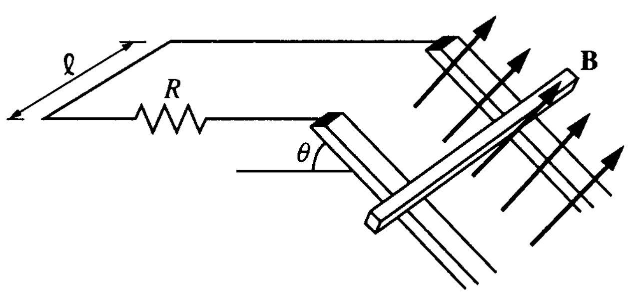
b. At time t = 0, the switch is moved to position A. Determine the voltmeter reading for the time immediately after t = 0.

c. After a long time, a measurement of potential difference across R_1 is again taken. Determine for this later time each of the following.
i. The voltmeter reading
ii. The charge on the capacitor

d. At a still later time t = T, the switch S is moved to position B. Determine the voltmeter reading for the time immediately after t = T.

e. A long time after t = T, the current in R_1 reaches a constant final value I_f.
i. Determine I_f.
ii. Determine the final energy stored in the inductor.

f. Write, but do not solve, a differential equation for the current in resistor R_1 as a function of time t after the switch is moved to position B.



1998E3. A conducting bar of mass m is placed on two long conducting rails a distance *l* apart. The rails are inclined at an angle θ with respect to the horizontal, as shown above, and the bar is able to slide on the rails with negligible friction. The bar and rails are in a uniform and constant magnetic field of magnitude B oriented perpendicular to the incline. A resistor of resistance R connects the upper ends of the rails and completes the circuit as shown. The bar is released from rest at the top of the incline. Express your answers to parts (a) through (d) in terms of m, *l*, θ, B, R, and g.

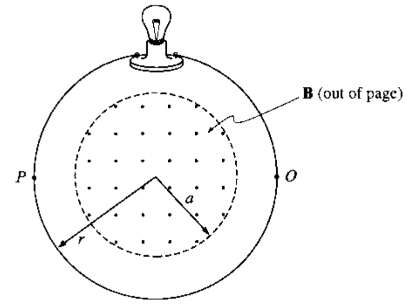
a. Determine the current in the circuit when the bar has reached a constant final speed.

b. Determine the constant final speed of the bar.

c. Determine the rate at which energy is being dissipated in the circuit when the bar has reached its constant final speed.

d. Express the speed of the bar as a function of time t from the time it is released at t = 0.

e. Suppose that the experiment is performed again, this time with a second identical resistor connecting the rails at the bottom of the incline. Will this affect the final speed attained by the bar, and if so, how? Justify your answer.

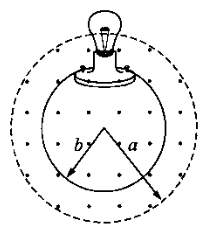


1999E2. A uniform magnetic field **B** exists in a region of space defined by a circle of radius a = 0.60 m as shown above. The magnetic field is perpendicular to the page and increases out of the page at a constant rate of 0.40 T/s. A single circular loop of wire of negligible resistance and radius r = 0.90 m is connected to a light bulb with a resistance R = 5.0 Ω, and the assembly is placed concentrically around the region of magnetic field.

a. Determine the emf induced in the loop.

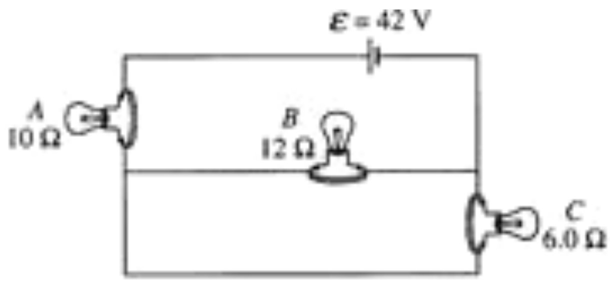
b. Determine the magnitude of the current in the circuit. On the figure above, indicate the direction of the current in the loop at point O.

c. Determine the total energy dissipated in the light bulb during a 15 s interval.



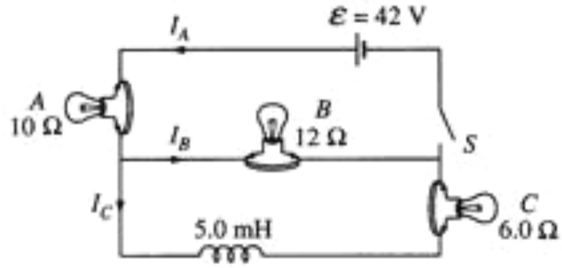
The experiment is repeated with a loop of radius b = 0.40 m placed concentrically in the same magnetic field as before. The same light bulb is connected to the loop, and the magnetic field again increases out of the page at a rate of 0.40 T/s. Neglect any direct effects of the field on the light bulb itself.

d. State whether the brightness of the bulb will be greater than, less than, or equal to the brightness of the bulb in part (a). Justify your answer.



2000E1. Lightbulbs A, B, and C are connected in the circuit shown above.

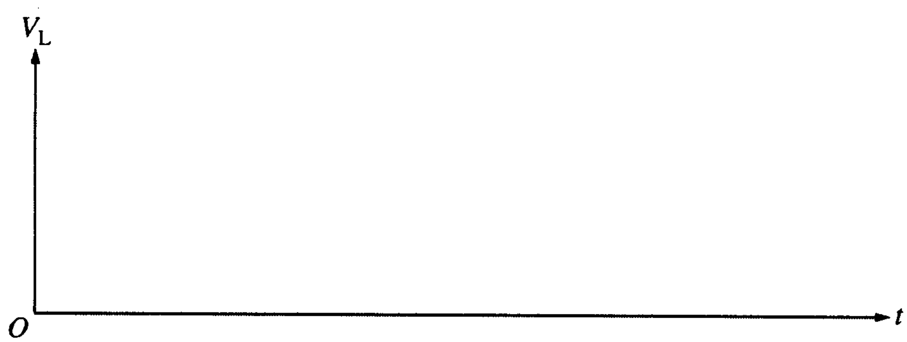
a. List the bulbs in order of their brightness, from brightest to least bright. If any bulbs have the same brightness, state which ones. Justify your answer.

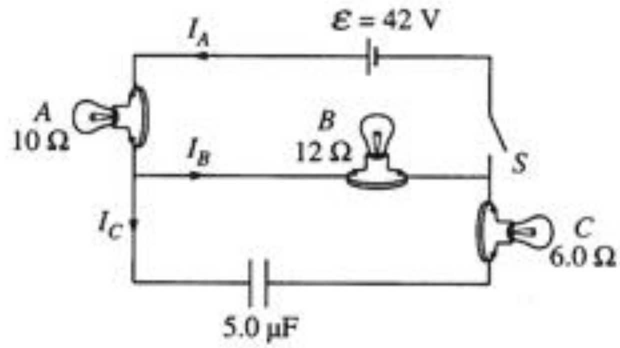


Now a switch S and a 5.0 mH inductor are added to the circuit; as shown above. The switch is closed at time t = 0.

b. Determine the currents I_A, I_B, and I_C for the following times.
   i. Immediately after the switch is closed
   ii. A long time after the switch is closed

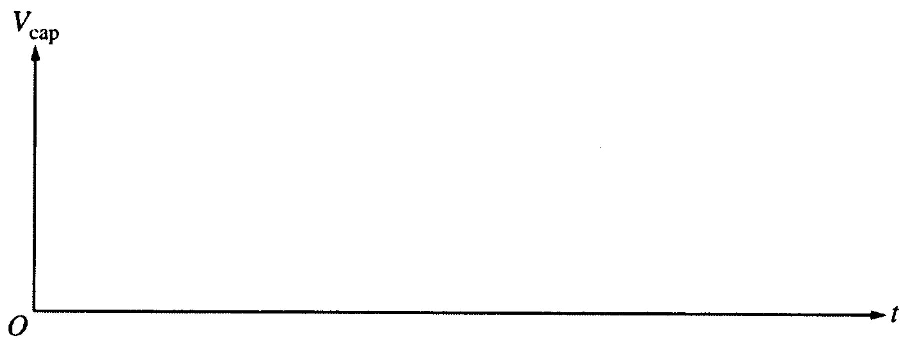
c. On the axes below, sketch the magnitude of the potential difference V_L across the inductor as a function of time, from immediately after the switch is closed until a long time after the switch is closed.

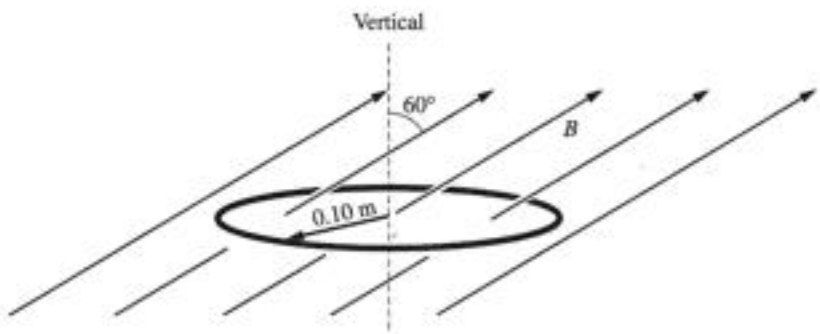




2000E1 [Continued]

d. Now consider a similar circuit with an uncharged 5.0 μF capacitor instead of the inductor, as shown above. The switch is again closed at time t = 0. On the axes below, sketch the magnitude of the potential difference V_{cap} across the capacitor as a function of time, from immediately after the switch is closed until a long time after the switch is closed.

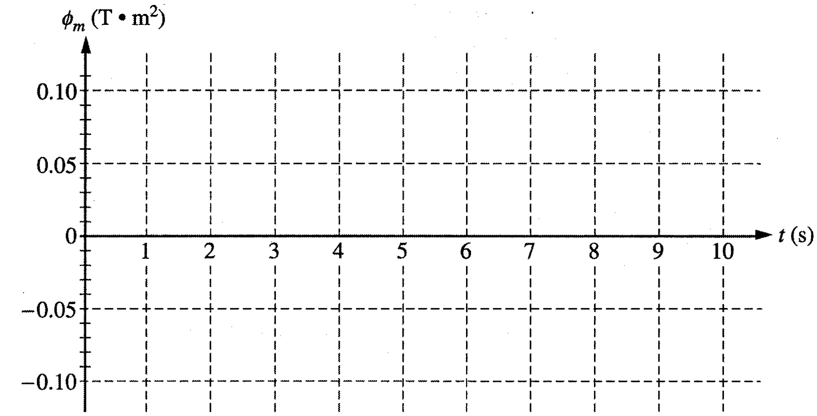




2002E3. A circular wire loop with radius 0.10 m and resistance 50 Ω is suspended horizontally in a magnetic field of magnitude B directed upward at an angle of 60° with the vertical, as shown above. The magnitude of the field in teslas is given as a function of time t in seconds by the equation $B = 4(1 - 0.2t)$.

a. Determine the magnetic flux Φ_m through the loop as a function of time.

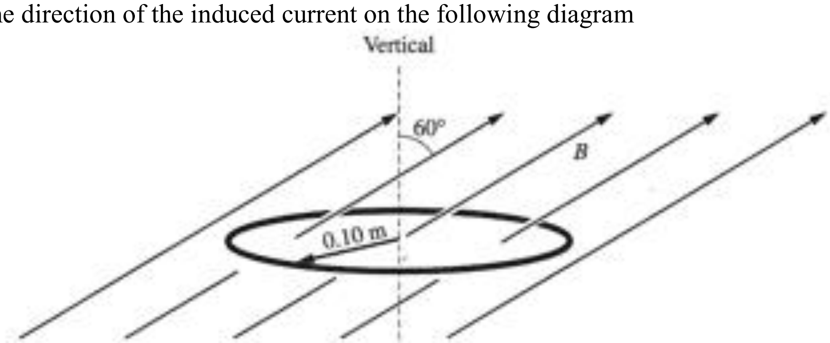
b. Graph the magnetic flux Φ_m as a function of time on the axes below.



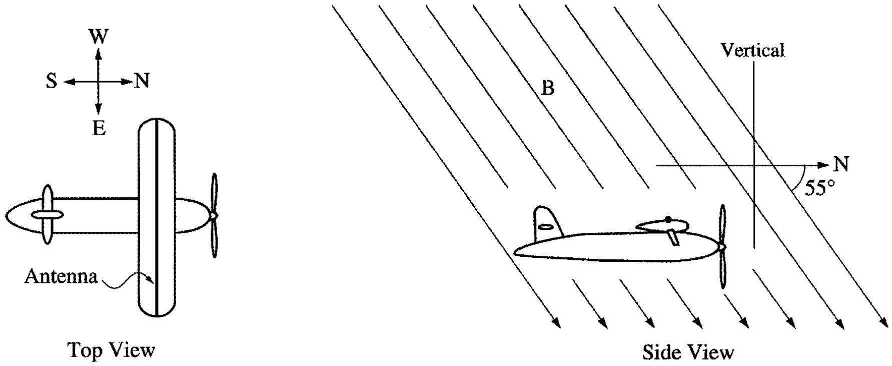
c. Determine the magnitude of the induced emf in the loop.

d. i. Determine the magnitude of the induced current in the loop.

ii. Show the direction of the induced current on the following diagram

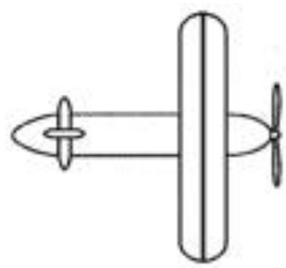


e. Determine the energy dissipated in the loop from t = 0 to t = 4 s



2003E3. 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.

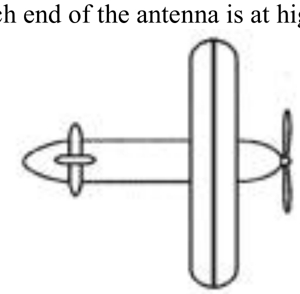
a. On the figure below, indicate the direction of the magnetic force on electrons in the antenna. Justify your answer.



b. Determine the magnitude of the electric field generated in the antenna.

c. Determine the potential difference between the ends of the antenna.

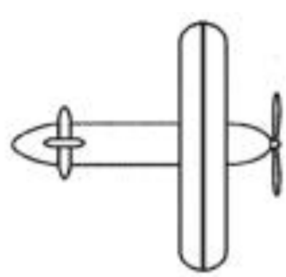
d. On the figure below, indicate which end of the antenna is at higher potential.

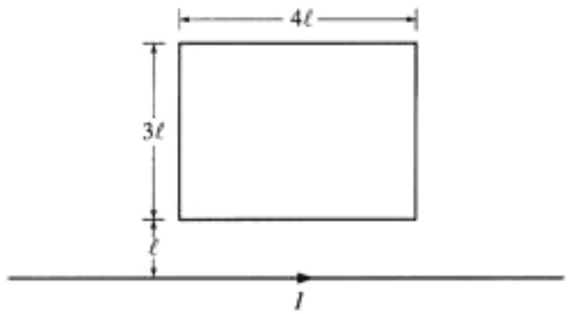


e. The ends of the antenna are now connected by a conducting wire so that a closed circuit is formed.

i. 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.

ii. For the example you gave in i. above, indicate the direction of the current in the antenna on the figure below.





2004E3. A rectangular loop of dimensions 3 ℓ and 4 ℓ lies in the plane of the page as shown above. A long straight wire also in the plane of the page carries a current I.

a. Calculate the magnetic flux through the rectangular loop in terms of I, ℓ , and fundamental constants.

Starting at time t = 0, the current in the long straight wire is given as a function of time t by $I(t) = I_0 e^{-kt}$, where I_0 and k are constants.

b. The current induced in the loop is in which direction?

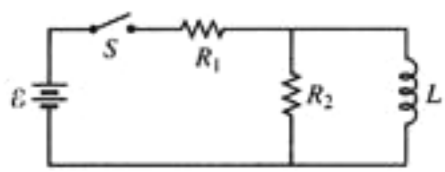
____Clockwise ____Counterclockwise

Justify your answer.

The loop has a resistance R. Calculate each of the following in terms of R, I_0 , k, ℓ , *and* fundamental constants.

c. The current in the loop as a function of time t

d. The total energy dissipated in the loop from t = 0 to $t = \infty$



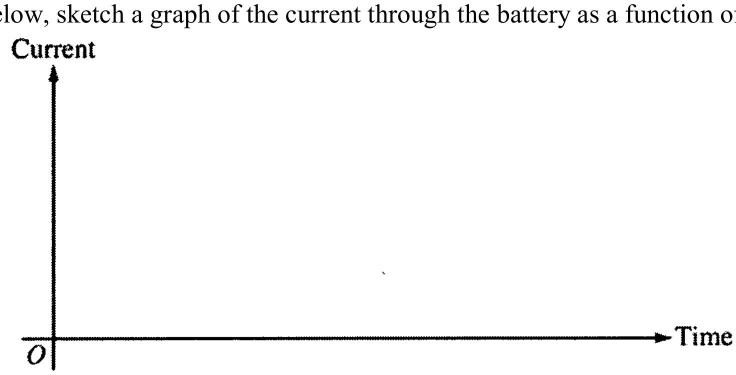
2005E2. In the circuit shown above, resistors 1 and 2 of resistance R_1 and R_2 , respectively, and an inductor of inductance L are connected to a battery of emf ε and a switch S. The switch is closed at time $t = 0$. Express all algebraic answers in terms of the given quantities and fundamental constants.

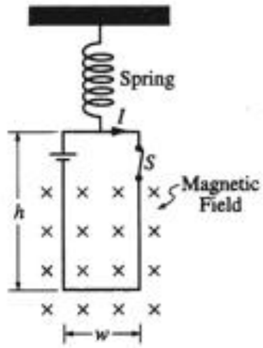
a. Determine the current through resistor 1 immediately after the switch is closed.

b. Determine the magnitude of the initial rate of change of current, dI/dt , in the inductor.

c. Determine the current through the battery a long time after the switch has been closed.

d. On the axes below, sketch a graph of the current through the battery as a function of time.





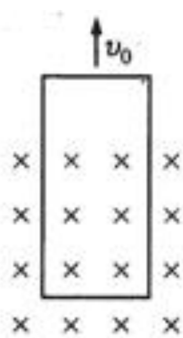
2006E3. A loop of wire of width w and height h contains a switch and a battery and is connected to a spring of force constant k, as shown above. The loop. carries a current I in a clockwise direction, and its bottom is in a constant, uniform magnetic field directed into the plane of the page.

a. On the diagram of the loop below, indicate the directions of the magnetic forces, if any, that act on each side of the loop.

b. The switch S is opened, and the loop eventually comes to rest at a new equilibrium position that is a distance x from its former position. Derive an expression for the magnitude B_0 of the uniform magnetic field in terms of the given quantities and fundamental constants.

The spring and loop are replaced with a loop of the same dimensions and resistance R but without the battery and switch. The new loop is pulled upward, out of the magnetic field, at constant speed v_o. Express algebraic answers to the following questions in terms of B_o, v_o, R, and the dimensions of the loop.

c. i. On the diagram of the new loop below, indicate the direction of the induced current in the loop as the loop moves upward.



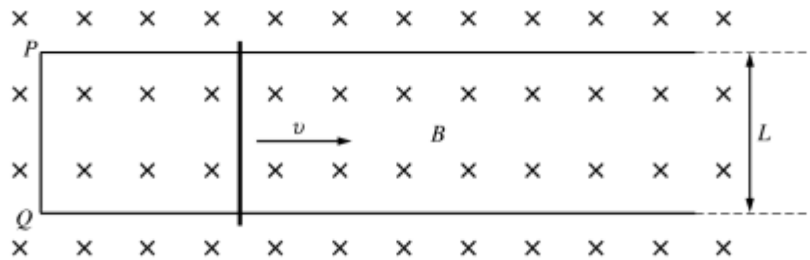
ii. Derive an expression for the magnitude of this current.

d. Derive an expression for the power dissipated in the loop as the loop is pulled at constant speed out of the field.

e. Suppose the magnitude of the magnetic field is increased. Does the external force required to pull the loop at speed v_o increase, decrease, or remain the same? .

_____ Increases _____Decreases _____Remains the same

Justify your answer.



2007E3. In the diagram above, a nichrome wire of resistance per unit length λ is bent at points P and Q to form horizontal conducting rails that are a distance L apart. The wire is placed within a uniform magnetic field of magnitude B pointing into the page. A conducting rod of negligible resistance, which was aligned with end PQ at time $t = 0$, slides to the right with constant speed v and negligible friction. Express all algebraic answers in terms of the given quantities and fundamental constants.

(a) Indicate the direction of the current induced in the circuit.

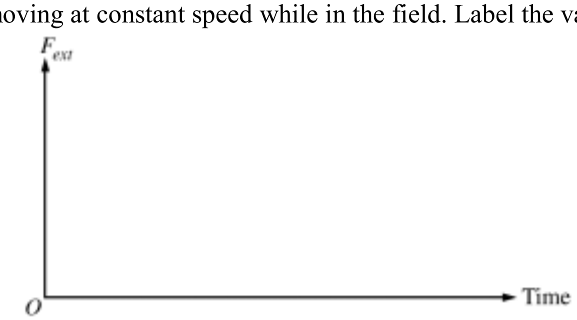
________Clockwise   ________Counterclockwise

Justify your answer.

(b) Derive an expression for the magnitude of the induced current as a function of time t.

(c) Derive an expression for the magnitude of the magnetic force on the rod as a function of time.

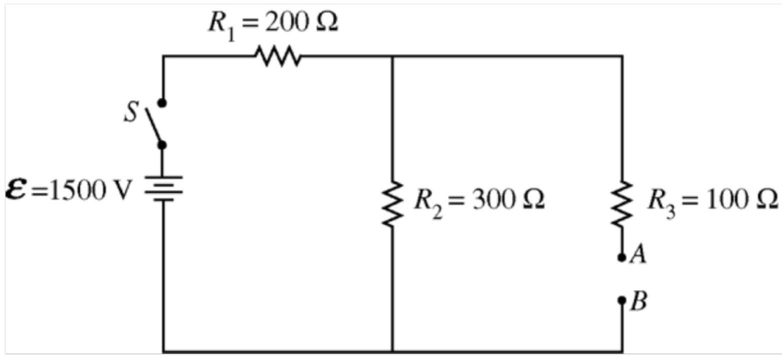
(d) On the axes below, sketch a graph of the external force F_{ext} as a function of time that must be applied to the rod to keep it moving at constant speed while in the field. Label the values of any intercepts.



(e) The force pulling the rod is now removed. Indicate whether the speed of the rod increases, decreases, or remains the same.

________Increases   ________Decreases   ________Remains the same

Justify your answer.



2008E2. In the circuit shown above, A and B are terminals to which different circuit components can be connected.

(a) Calculate the potential difference across R_2 immediately after the switch S is closed in each of the following cases.

i. A 50 Ω resistor connects A and B.

ii. A 40 mH inductor connects A and B.

iii. An initially uncharged 0.80 μF capacitor connects A and B.

(b) The switch gets closed at time $t = 0$. On the axes below, sketch the graphs of the current in the 100 Ω resistor R_3 versus time t for the three cases. Label the graphs R for the resistor, L for the inductor, and C for the capacitor.

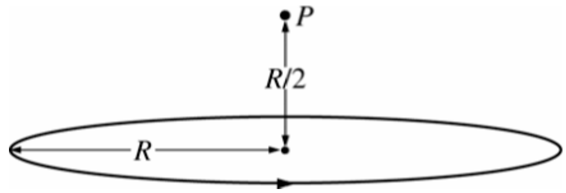


Figure 1

2008E3. The circular loop of wire in Figure 1 above has a radius of R and carries a current I. Point P is a distance of R/2 above the center of the loop. Express algebraic answers to parts (a) and (b) in terms of R, I, and fundamental constants.

(a)

i. State the direction of the magnetic field B_1 at point P due to the current in the loop.

ii. Calculate the magnitude of the magnetic field B_1 at point P.

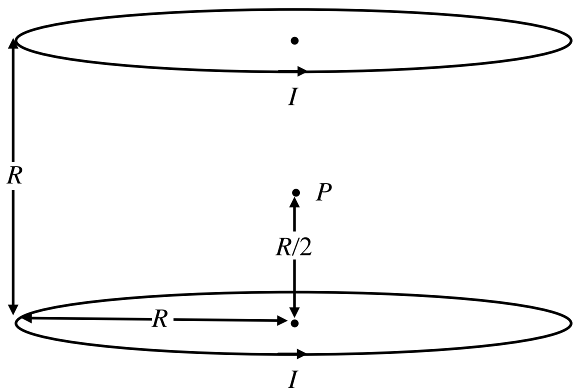


Figure 2

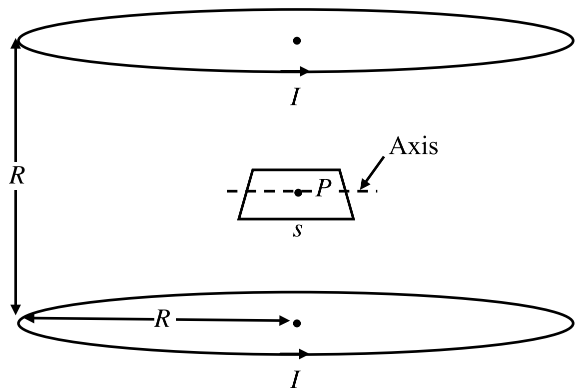


Figure 3

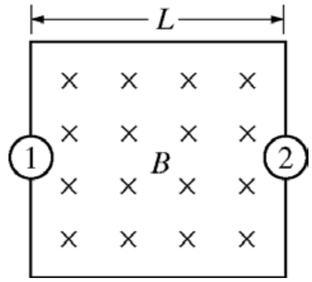
A second identical loop also carrying a current I is added at a distance of R above the first loop, as shown in Figure 2 above.

(b) Determine the magnitude of the net magnetic field B_{net} at point P.

A small square loop of wire in which each side has a length s is now placed at point P with its plane parallel to the plane of each loop, as shown in Figure 3 above. For parts (c) and (d), assume that the magnetic field between the two circular loops is uniform in the region of the square loop and has magnitude B_{net}.

(c) In terms of B_{net} and s, determine the magnetic flux through the square loop.

(d) The square loop is now rotated about an axis in its plane at an angular speed ω. In terms of B_{net}, s, and ω, calculate the induced emf in the loop as a function of time t, assuming that the loop is horizontal at $t = 0$.



2009E3.

A square conducting loop of side L contains two identical lightbulbs, 1 and 2, as shown above. There is a magnetic field directed into the page in the region inside the loop with magnitude as a function of time t given by $B(t) = at + b$, where a and b are positive constants. The lightbulbs each have constant resistance R_0 .Express all answers in terms of the given quantities and fundamental constants.

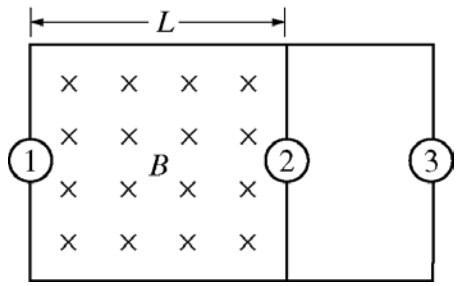
(a) Derive an expression for the magnitude of the emf generated in the loop.

(b) i. Determine an expression for the current through bulb 2.

ii. Indicate on the diagram above the direction of the current through bulb 2.

(c) Derive an expression for the power dissipated in bulb 1.

Another identical bulb 3 is now connected in parallel with bulb 2, but it is entirely outside the magnetic field, as shown below.

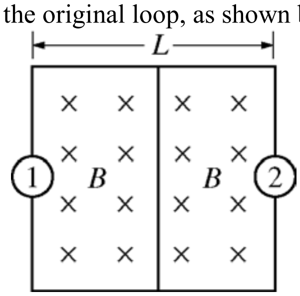


(d) How does the brightness of bulb 1 compare to what it was in the previous circuit?

____ Brighter ____ Dimmer ____ The same

Justify your answer.

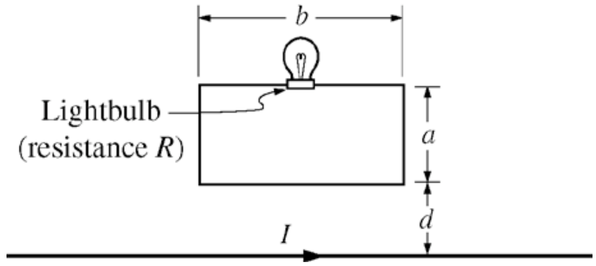
Now the portion of the circuit containing bulb 3 is removed, and a wire is added to connect the midpoints of the top and bottom of the original loop, as shown below.



(e) How does the brightness of bulb 1 compare to what it was in the first circuit?

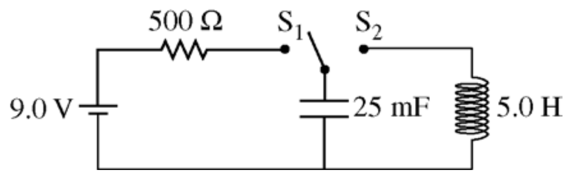
____ Brighter ____ Dimmer ____ The same

Justify your answer.



2010E3. The long straight wire illustrated above carries a current I to the right. The current varies with time t according to the equation $I = I_0 - Kt$, where I_0 and K are positive constants and I remains positive throughout the time period of interest. The bottom of a rectangular loop of wire of width b and height a is located a distance d above the long wire, with the long wire in the plane of the loop as shown. A lightbulb with resistance R is connected in the loop. Express all algebraic answers in terms of the given quantities and fundamental constants.

a. Indicate the direction of the current in the loop.
   ____Clockwise ____Counterclockwise
   Justify your answer.
b. Indicate whether the lightbulb gets brighter, gets dimmer, or stays the same brightness over the time period of interest.
   ____Gets brighter ____Gets dimmer ____Remains the same
   Justify your answer.
c. Determine the magnetic field at $t = 0$ due to the current in the long wire at distance r from the long wire.
d. Derive an expression for the magnetic flux through the loop as a function of time.
e. Derive an expression for the power dissipated by the lightbulb.

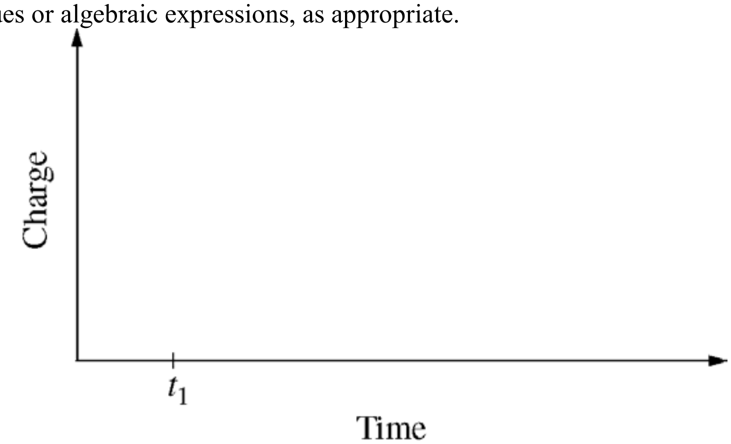


2011E2. The circuit represented above contains a 9.0 V battery, a 25 mF capacitor, a 5.0 H inductor, a 500 Ω resistor, and a switch with two positions, S_1 and S_2. Initially the capacitor is uncharged and the switch is open.

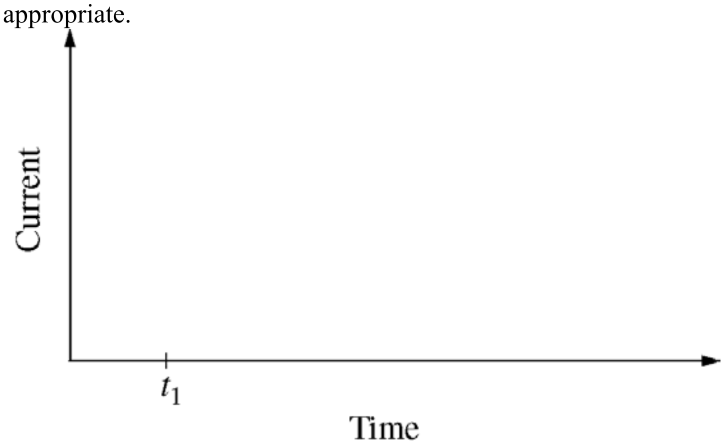
(a) In experiment 1 the switch is closed to position S_1 at time t_1 and left there for a long time.

i. Calculate the value of the charge on the bottom plate of the capacitor a long time after the switch is closed.

ii. On the axes below, sketch a graph of the magnitude of the charge on the bottom plate of the capacitor as a function of time. On the axes, explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.



iii. On the axes below, sketch a graph of the current through the resistor as a function of time. On the axes, explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.



(b) In experiment 2 the capacitor is again uncharged when the switch is closed to position S_1 at time t_1 . The switch is then moved to position S_2 at time t_2 when the magnitude of the charge on the capacitor plate is 105 mC, allowing electromagnetic oscillations in the *LC* circuit.

i. Calculate the energy stored in the capacitor at time t_2 .

ii. Calculate the maximum current that will be present during the oscillations.

iii. Calculate the time rate of change of the current when the charge on the capacitor plate is 50 mC.

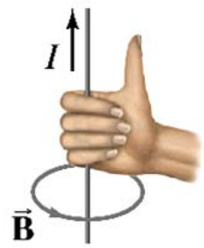
ANSWERS - AP Physics C Multiple Choice Practice – Magnetism

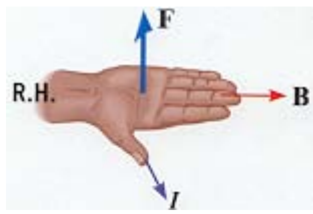
SECTION A – Magnetostatics

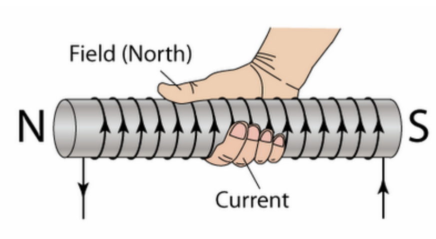
Solution — Answer

For the purposes of this solution guide. The following hand rules will be referred to.
RHR means right hand rule (for + current). LHR will be substituted for – current

RHR (Ampere) — RHR (force) — RHR (Solenoid)







1. RHR (force), since electrons drift east, we can consider conventional current flowing west. With the thumb of your right hand west and finders pointing north (along B), the palm faces vertically downward — **E**

2. Since the particle is moving parallel to the field it does not cut across lines and has no force. — **D**

3. The electric force would act upwards on the proton so the magnetic force would act down. Using RHR (force), the B field must point out of the page — **D**

4. $F_e = F_b$ $\quad$ $Eq = qvB$ $\quad$ $E = vB$ $\quad$ $B = E/v$ — **A**

5. Magnetic fields do no work on charged particles as the force is perpendicular to the displacement — **E**

6. RHR (force) — **E**

7. Based on … $F_{net(C)} = mv^2/r$ … $F_b = mv^2/r$ … $qvB = mv^2/r$ … $r = mv/qB$ … inverse — **B**

8. Isolating poles/charges is Gauss's Law. In magnetic form, Gauss's Law is $\int BdA$ and the absence of magnetic monopoles leads to the integral equal to zero — **C**

9. Based on the axis given. The left side wire is on the axis and makes no torque. The top and bottom wires essentially cancel each other out due to opposite direction forces, so the torque can be found from the right wire only. Finding the force on the right wire …
$F_b = BIL = (0.05)(2)(0.3) = .03$ N, then torque $= Fr = (0.03)(0.3)$ — **B**

10. When a particle has components parallel and perpendicular to a magnetic field, the perpendicular component will lead to circular motion while the parallel component will remain unchanged, leading to a forward moving circular path around the field line — **D**

11. Using RHR(force) for the magnetic field direction given, the magnetic force would be up (+z). To counteract this upwards force on the + charge, the E field would have to point down (– z). — **E**

12. First we have … $F_{net(C)} = mv^2/r$ … $F_b = mv^2/r$ … $qvB = mv^2/r$ … $v = qBr/m$
Then using $v = 2\pi R / T$ we have $qBr/m = 2\pi R / T$ … radius cancels so period is unchanged and frequency also is unaffected by the radius. Another way to think about this with the two equations given above is: by increasing R, the speed increases, but the $2\pi R$ distance term increases the same amount so the time to rotate is the same — **A**

13. Pick any small segment of wire. The force should point to the center of the circle. For any small segment of wire, use RHR (force) and you get velocity direction is CCW. Equation is the same as the problem above … $qvB = mv^2/r$ … $eBr = mv$ — **C**

14. Same as in question 12 … $qBr/m = 2\pi R / T$ … $T = 2\pi m / eB$ C

15. A little tricky since its talking about fields and not forces. To move at constant velocity the magnetic FORCE must be opposite to the electric FORCE. Electric fields make force in the same plane as the field (ex: a field in the x plane makes a force in the x plane), but magnetic fields make forces in a plane 90 degrees away from it (ex: a field in the x plane can only make magnetic forces in the y or z plane). So to create forces in the same place, the fields have to be perpendicular to each other B

16. The left and right sides of the loop wires are parallel to the field and experience no forces. Based on RHR (force), the top part of the loop would have a force out of the page and the bottom part of the loop would have a force into of the page which rotates as in choice C C

17. With electrons drifting toward the bottom of the page and a magnetic field into the page, the left hand rule for forces give a force on the electrons toward the left. This would cause the left side of the copper sheet to acquire a negative charge, a lower potential than the right side. B

SECTION B – Biot Savart and Ampere's Law

18. The force on either wire is $F_b = (\mu_o I_a / 2\pi R)\, I_b L$ D

19. In a cylindrical wire with a uniform current, B is proportional to r inside the wire and proportional to 1/r outside the wire A

20. For long (ideal) solenoids, $B = \mu_0 In$, there is no dependence on radius C

21. Using RHR (Ampere) for each wire, the left wire makes a field pointing down&right at P and the right wire makes a field pointing up&right. The up and down parts cancel leaving only right E

22. In a cylindrical wire with a uniform current, B is proportional to r inside the wire and proportional to 1/r outside the wire E

23. Wires with current flowing in the same direction attract B

24. $F_b = (\mu_o I_a / 2\pi R)\, I_b L$ … R is ×2 and both I's are ×2 so it's a net effect of ×2 D

25. Using RHR (Solenoid), the B field at the center of that loop is directed right. Since the other loop is further away, its direction is irrelevant at the left loop will dominate C

26. For long (ideal) solenoids, $B = \mu_0 In$, there is no dependence on radius E

27. The field from a single wire is given by $\mu_o I_a / 2\pi R$. The additional field from wire Y would be based on this formula with R = 3R, so in comparison it has 1/3 the strength of wire X. So adding wire X's field B_o + the relative field of wire Y's of 1/3 B_o gives a total of 4/3 B_o D

28. Using dimensional analysis: meters/second = meters/proton × protons/coulomb × coulombs/second = current ÷ charge of a proton ÷ protons per meter = $1.6 \times 10^{-3} \div 1.6 \times 10^{-19} \div 10^{9}$ D

29. By RHR (Ampere) A

30. First we use RHR (Ampere) to find the B field above the wire as into the page, and we note that the magnitude of the B field decreases as we move away from it. Since the left AB and right CD wires are sitting in the same average value of B field and have current in opposite directions, they repel each other and those forces cancel out. Now we look at the wire AD closest to the wire. Using RHR (force) for this wire we get down as a force. The force on the top wire BC is irrelevant because the top and bottom wires have the same current but the B field is smaller for the top wire so the bottom wire will dominate the force direction no matter what. Therefore, the direction is down towards the wire A

31. Like Gauss's Law, Ampere's Law is useful for certain geometries where the magnetic field is of a particular special nature that lends itself to a line integral easily. Choices A and B have zero magnetic fields and choices D and E do not have magnetic fields that are easily integrable — C

32. The path integral around the Amperian loop is $2\pi r$. Inside a wire, the current enclosed in our Amperian loop is proportional to the fractional area enclosed ($\pi r^2/\pi R^2$) — B

33. $F = \mu_0 I_1 I_2 L/2\pi d$ — C

34. Each wire creates a magnetic field around itself. Since all the currents are the same, and wire Y is closer to wire X, wire X's field will be stronger there and dominate the force on wire Y. So we can essentially ignore wire Z to determine the direction of the force. Since X and Y are in the same direction they attract and Y gets pulled to the left — E

SECTION C – Induction and Inductance

35. As long as the flux inside the loop is changing, there will be an induced current. Since choice E has both objects moving in the same direction, the flux through the loop remains constant so no need to induce a current — E

36. Since the bar is not cutting across field lines and has no component in a perpendicular direction to the field line there will be no induced emf — B

37. As you enter the region, flux into the page is gained. To counteract that, current flows to create a field out of the page to maintain flux. Based on RHR–solenoid, that current is CCW. When leaving the region, the flux into the page is decreasing so current flows to add to that field which gives CW — A

38. When establishing a current through an inductor, the back emf initially opposes all current so the current (and V_R) is zero. Over time the current (and V_R) increases to its steady value as the back emf reduces to zero — B

39. First use $\mathcal{E} = \Delta\Phi / t$ $\quad \mathcal{E} = (BA_f – BA_i) / t$ $\quad \mathcal{E} = (0–(0.4)(0.5\times0.5))/2$ $\quad \mathcal{E} = 0.05$ V — B
Then use V=IR 0.05V = I(.01) I = 5A
Direction is found with Lenz law. As the field out decreases, the current flows to add outward field to maintain flux. Based on RHR–solenoid, current flows CCW

40. Voltage = L(dI/dt) so 1 H = V-s/A and 1 Ω = 1 V/A so 1 H/1 Ω = V-s/A ÷ V/A — E

41. Loop 2 initially has zero flux. When the circuit is turned on, current flows through loop 1 in a CW direction, and using RHR–solenoid it generates a B field down towards loop 2. As the field lines begin to enter loop 2, loop 2 has current begin to flow based on lenz law to try and maintain the initial zero flux so it makes a field upwards. Based on RHR–solenoid for loop 2, current would have to flow CCW around that loop which makes it go from X to Y — A

42. After a long time, the flux in loop 2 becomes constant and no emf is induced so no current flows. In circuit 1, the loop simply acts as a wire and the current is set by the resistance and V=IR — C

43. From Ampere-Maxwell's equation, the effect of a changing electric field between the plates of a charging capacitor are identical in the production of a magnetic field as a current through a wire (this is the displacement current) and is proportional to this rate of change as it is proportional to a current. — B

44. When establishing a current through an inductor, the back emf initially opposes all current so the current through that branch is zero — A

45. After steady current has been established, the inductor has no more effect on the currents in the circuit and acts as if it were not present B

46. When the switch is opened, the inductor keeps the existing current (opposing the change), but as the energy in the inductor diminishes, the current decays to zero asymptotically E

47. As the magnet moves down, flux increase in the down direction. Based on Lenz law, current in the loop would flow to create a field upwards to cancel the increasing downwards field. Using RHR–solenoid, the current would flow CCW. Then, when the magnet is pulled upwards, you have downward flux lines that are decreasing in magnitude so current flows to add more downward field to maintain flux. Using RHR–solenoid you now get CW E

48. Since the wire is not cutting across the field lines, there is no force and no charge separation E

49. $I = \mathcal{E}/R = (dB/dt)A/R = bL^2/R$. Since the field is decreasing in strength over time (that is, increasing into the page) the induced current will establish a field pointing out of the page to oppose this change and by RHR-solenoid, this is counterclockwise E

50. By RHR-solenoid, the current loop establishes a south pole on the side near the magnet, attracting it A

51. $\mathcal{E} = (-dB/dt)A$ so $B = -(1/A)\int E\, dt = -(1/A)\int bAt^{1/2}\, dt$ E

52. If $R = at$, the area is $A = \pi R^2 = \pi a^2t^2$ and the induced emf is $B(dA/dt) = B(2\pi a^2 t)$ A

53. As the loop is pulled to the right, it loses flux lines right so current is generated by Lenz law to add more flux lines right. This newly created field to the right from the loop is in the same direction as the magnetic field so makes an attractive force pulling the magnet right also A

54. $\int Eds$ is potential difference. A potential difference equal to the rate of change of some flux is Faraday's Law, which involves magnetic flux. A

55. After steady current has been established, the inductor has no more effect on the currents in the circuit and acts as if it were not present C

56. When establishing a current through an inductor, the back emf initially opposes all current so the current (and V_R) is zero A

SECTION A – Magnetostatics

1976E3

a. In order to move in a uniform circular path, the force must be directed toward the center of the circle.
b. Because the particle experiences an upward magnetic force while traveling to the right in a magnetic field pointing out of the page, it is the LHR that provides the correct direction, which indicates a negative charge.
c. The magnetic force acts up and the electric force acts down
d. As there is no acceleration in region I, the net force must be zero, so the magnetic force is equal to the electric force: $qvB = qE$, or $v = E/B$
e. In the circular region $F = mv^2/r = qvB$ with $v = E/B$, giving $m = B^2qR/E$

1977E3

a. Counterclockwise. The current flows radially outward, use RHR (force)
b. $\tau = rF$ for each spoke and let r = center of mass of each spoke:
$Nr(BIL) = (6)(0.1\text{ m})(0.5\text{ T})(6\text{ A})(0.2\text{ m}) = 0.06$ N-m

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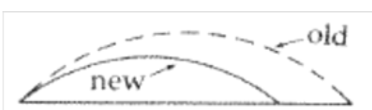
1978E1

a. $\Delta U = \Delta K$
$qV_g = ½\, mv_e^2$ giving $v_e = (2eV_g/m)^{1/2}$
b. Total energy upon entering = total energy at y_{max}
$½\, mv_e^2 = ½\, mv_e^2\cos^2\theta + e(V_P/d)y_{max}$ where the second term is from $W = qEd$
thus $y_{max} = d(V_g/V_P)\sin^2\theta$
c. The speed at impact is unchanged, the magnetic force is always 90º to the velocity and thus does no work
d.



Along the old path, the magnetic force always had a downward component, thus y_{max} is lower ands the time of flight shorter.

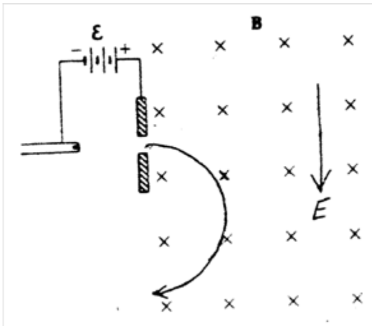
1979E3

a. Experiment I demonstrated that B is in the plane of the page because F is perpendicular to both v and B
Experiment II demonstrates that B makes an angle of –60º (to the x axis) in the plane of the paper since it must be perpendicular to F_2
b. For the motion to be purely circular F must be perpendicular to v and the force is constant, while v is also perpendicular to B, this is case II. Since $F = mv^2/r$ we have $r = mv^2/F$
c. Since v is not perpendicular to B, the component of v parallel to v produces no force and hence no change in motion. The perpendicular component of the velocity produces circular motion. The resulting motion is spiral (helix) about the B vector.

1984E1

a. $q\mathcal{E} = \frac{1}{2} mv^2$ gives $\mathcal{E} = mv^2/2e$

b. and d.ii.



c. $F_B = mv^2/r$

$r = mv/eB$

d. i. $F_E = F_B$; $qE = qvB$ giving $E = vB$

1990E2

a. Based on the RHR, the magnetic force on the + charge is down, so the electric force should point up. For + charges, and E field upwards would be needed to make a force up.
b. The speed on region III is equal the whole time and is the same as the speed of the particles in region II. For region II we have … $F_e = F_b$ … $Eq = qvB$ … $v = E/B$
c. Using region III … $F_{net(C)} = mv^2/r$ … $qvB = mv^2/r$ … $m = QBR/v$ (sub in v) … $= QB^2R/E$
d. In between the plates, $W = K$ … $Vq = \frac{1}{2} mv^2$ … $V = mv^2/2Q$ … (sub in v and m) … $= RE/2$
e. In region three, the acceleration is the centripetal acceleration. $a_c = v^2/R$ … (sub in v) … E^2/RB^2
f. Time of travel can be found with $v = d/t$ with the distance as half the circumference $(2\pi R/2)$ then sub in v giving … $t = \pi RB/E$

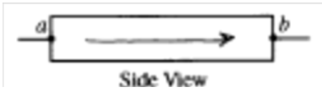
1993E3

a. The magnetic force provides the centripetal force. By RHR (force) we get B points into the page or –z
b. Between the plates, the electric field must exert a force opposite to the magnetic force. The magnetic force is to the right so the electric force must point to the left and since the charge is positive, the field must also point to the left. Therefore, plate K should have a positive polarity with respect to plate L
c. $E = V/d = (1500\ V)/(0.012\ m) = 1.25 \times 10^5\ V/m$
d. $F_E = F_B$; $qE = qvB$ giving $v = E/B = 6.25 \times 10^5\ m/s$
e. $F_B = mv^2/R = qvB$ giving $m = qBR/v = 2.56 \times 10^{-26}\ kg$
f. Using the equation from (e) and solving for R gives $R = mv/qB$. Replacing q with 2q gives $R' = R/2 = 0.25\ m$

2009E2

a. $R = \rho L/A = 7.2\ \Omega$ and $P = V^2/R = 11$ W

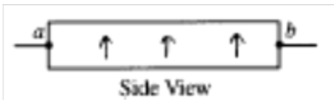
b.



c. $E = V/d = (9\text{ V})/(0.08\text{ m}) = 110$ V/m

d. $F = ILB = VLB/R = 0.025$ N

e.



f. $F_E = F_B$; $qE = qvB$ giving $E = vB = 8.8 \times 10^{-4}$ V/m

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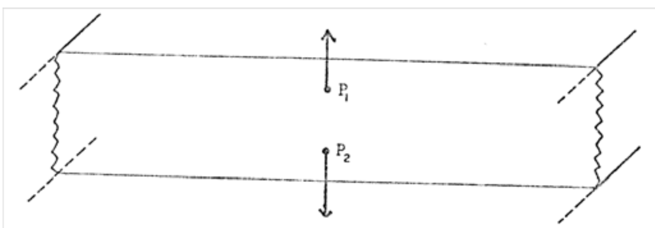
SECTION B – Biot Savart and Ampere's Law

1979E2

a.

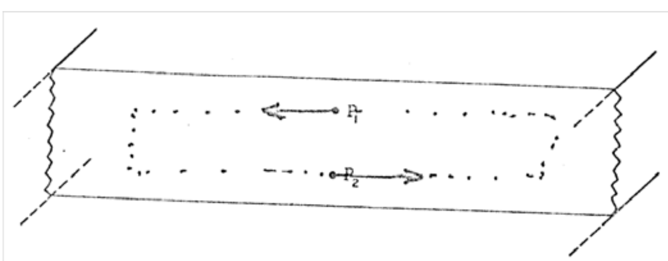


b.

$$\oint E \cdot dA = \frac{Q_{enc}}{\varepsilon_0}$$

Choose a pill-box with a top and bottom area A. Let the top face pass through P_1 and the bottom through P_2. By symmetry, E is perpendicular to both ends, is directed outward and is of equal magnitude (and parallel to the sides). $Q_{enc} = \rho(2a)(A)$ Thus $2EA = \rho(2a)(A)/\varepsilon_0$ giving $E = \rho a/\varepsilon_0$

c.



d.

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 i_{enc}$$

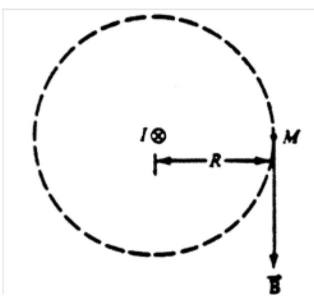
Choose a rectangular path of length L and width 2a with the top and bottom through P_1 and P_2. By symmetry, B is parallel to both the top and bottom, is in the same direction as the path increment and is normal to the ends $2BL = \mu_0 i = \mu_0 j2AL$ giving $B = \mu_0 aj$

1981E2

a. E points to the right, along the axis
b. From each small charge element $dE = kdq/r^2$ and we only consider the axial components, that is $dE \cos\theta$ where $\cos\theta = b/(a^2 + b^2)^{1/2}$ and since each point of the ring is the same distance we only integrate dq to Q giving $E = kbQ/(a^2 + b^2)^{3/2}$
c. $I = Q/T = Q/(2\pi/\omega) = Q\omega/2\pi$
d. By RHR (ampere) the field points axially to the left
e. By the RHR and symmetry, we know that the NET B is to the left. Thus only the horizontal component of B is important. To find the angle, let us examine the top portion of the ring. The straight line r vector from this portion to P is at an angle of theta ($\cos\theta = a/r$) from the vertical. The field at P due to this top portion is perpendicular to this r vector--down and to the left, at the same angle θ, but from the horizontal. Thus the only component of dB that is important is $dB \cos\theta = dB \times a/(a^2 + b^2)^{1/2}$
$dB_x = \mu_0 I dl/4\pi(a^2 + b^2)$ where $dl = a\, d\theta$. And $I\, d\theta = Q\, d\theta/dt = Q\omega$ which gives $B = \mu_0 \omega a^2 Q/4\pi(a^2 + b^2)^{3/2}$

1983E3

a.

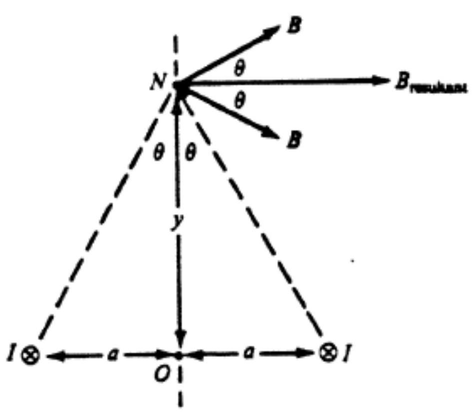


The field at M is down, the path of integration is a circle around I.

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 i_{enc}$$

Applied to the circular path gives $B(2\pi R) = \mu_0 I$ so that $B = \mu_0 I/2\pi R$

b. i. The field from a wire is given by $B = \mu_o I / (2\pi R)$, with R and I equal for both wires at point O. Based on the RHR for the current wires, the right wire makes a field down and the left wire makes a field up so cancel to zero.



ii. Based on the RHR, the resultant fields from each wire are directed as shown. Since the distance to each wire is the same, the resultant B field will simply be twice the x component of one of the wire's B fields.

The distance to point N is $\sqrt{a^2 + y^2}$ so the total field at that location from a single wire is

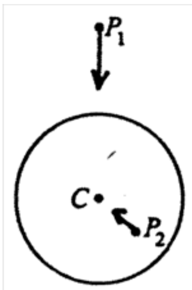
$$B = \frac{\mu_o I}{2\pi\sqrt{a^2 + y^2}}$$

The x component of that field is given by $B \cos\theta$, where $\cos\theta$ can be replaced with $\cos\theta = a/h = y/\sqrt{a^2 + y^2}$

Giving $B_{net} = 2B\cos\theta = 2B\ y/\sqrt{a^2 + y^2} = \dfrac{2y\mu_o I}{2\pi\sqrt{a^2 + y^2}\sqrt{a^2 + y^2}} = \dfrac{y\mu_o I}{\pi(a^2 + y^2)}$

1993E1

a.



b. i.

$$\oint E \cdot dA = \frac{Q_{enc}}{\varepsilon_0}$$

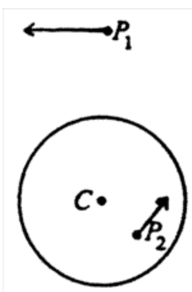
For r > R using a Gaussian surface that is a cylinder of radius r and length L, $Q_{enc} = \rho(\pi R^2 L)$

$E(2\pi rL) = \rho(\pi R^2 L)/\varepsilon_0$ so $E = \rho R^2/2\varepsilon_0 r$

ii. For r < R, use a similar Gaussian surface as above and $Q_{enc} = \rho(\pi r^2 L)$

$E(2\pi rL) = \rho(\pi r^2 L)/\varepsilon_0$ so $E = \rho r/2\varepsilon_0$

c.



d.

$$\oint \vec{B} \cdot \overrightarrow{dl} = \mu_0 i_{enc}$$

Where I_{enc} is the current enclosed by the closed Amperian loop (current density times area) = $(I/\pi R^2)(\pi r^2)$

For r < R: $B(2\pi r) = \mu_0(I/\pi R^2)(\pi r^2)$ gives $B = \mu_0 Ir/2\pi R^2$

1994E3

a.

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 i_{enc}$$

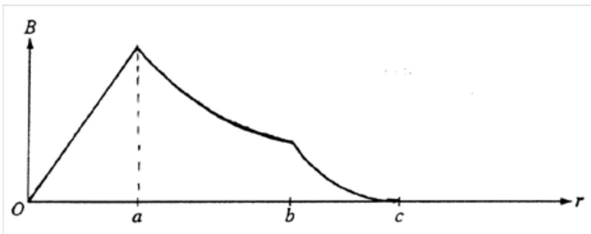
Where I_{enc} is the current enclosed by the closed Amperian loop (current density times area) = $(I/\pi a^2)(\pi r^2)$

i. For r < a: $B(2\pi r) = \mu_0(I/\pi a^2)(\pi r^2)$ gives $B = \mu_0 Ir/2\pi a^2$

ii. For a < r < b: $B(2\pi r) = \mu_0 I$ gives $B = \mu_0 I/2\pi r$

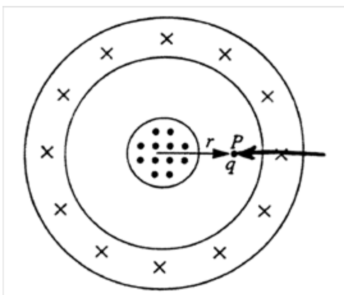
b. For r > c the net current enclosed is zero therefore the field is also zero

c.



d. i. $F = qvB = qv\mu_0 I/2\pi r$

ii.



Cross Section

e. The answers to (d) would not change, only the current inside the radius r has any effect on the magnetic field and hence, the charge

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2000E3

a. i.

$$\oint E \cdot dA = \frac{Q_{enc}}{\varepsilon}$$

Where we have replaced ε_0 with $\varepsilon = \kappa\varepsilon_0$

$E(2\pi rL) = Q/\kappa\varepsilon_0$

$E = Q/2\pi\kappa\varepsilon_0 rL$

ii. E = 0 (net charge enclosed is zero)

b. i. $\Delta V = \int E dr = (Q/2\pi\kappa\varepsilon_0 L)\int dr/r$ (limits from a to b) $= (Q/2\pi\kappa\varepsilon_0 L)\ln(b/a)$

ii. $C = Q/\Delta V = 2\pi\kappa\varepsilon_0 L/\ln(b/a)$

c. i.

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 i_{enc}$$

$B(2\pi r) = \mu_0(\mathcal{E}/R)$ gives $B = \mu_0\mathcal{E}/2\pi rR$

ii. $B(2\pi r) = \mu_0(4\mathcal{E}/R)$ gives $B = 2\mu_0\mathcal{E}/\pi rR$

2001E3

a. $I = \mathcal{E}/R$ the current flows clockwise, or to the left through the rod

b. Currents in opposite directions repel so the current in the cable must be to the right

c. $F = IlB = mg = I_c l\mu_0\mathcal{E}/2\pi rR$ giving $I_c = 2\pi mgrR/\mu_0 l\mathcal{E}$

d. $\phi = \int BdA$ where $B = \mu_0 I_c/2\pi x$ and x is the vertical distance from the cable and $dA = ldx$

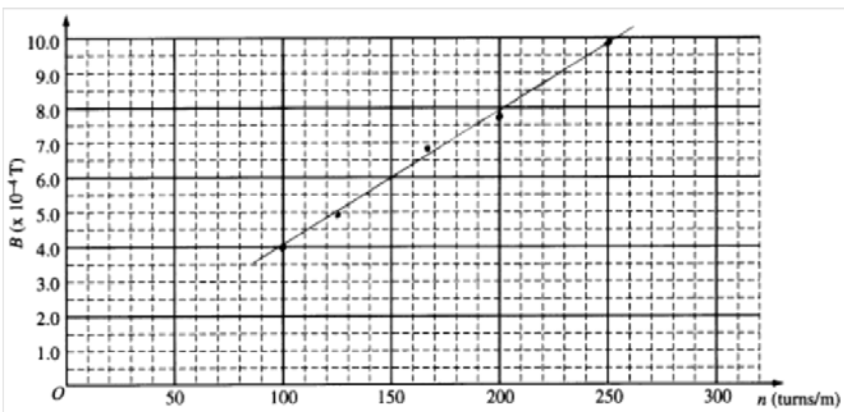
$$\phi = \int_r^{r+d} \frac{\mu_0 2\pi mgrRl}{2\pi\mu_0 l\varepsilon}\frac{dx}{x} = \frac{mgrR}{\varepsilon}\ln x\Big|_r^{r+d} = \frac{mgrR}{\varepsilon}\ln\left(\frac{r+d}{r}\right)$$

2005E3

a.

Trial	Position of End Q (cm)	Measured Magnetic Field (T) (directed from P to Q)	n (turns/m)
1	40	9.70×10^{-4}	250
2	50	7.70×10^{-4}	200
3	60	6.80×10^{-4}	167
4	80	4.90×10^{-4}	125
5	100	4.00×10^{-4}	100

b.



c. $B = \mu_0 In$ gives $\mu_0 I$ = slope of line = $\Delta B/\Delta n = (9.5 - 4.5) \times 10^{-4}$ T/(240 – 110) turns/m = 5×10^{-4} T/130 turns/m
μ_{0exp} = (1/3 A)(5×10^{-4} T/130 turns/m) = 1.3×10^{-6} (T-m)/A

d. percent error = $100 \times (\mu_0 - \mu_{0exp})/\mu_0 = -3.5\%$

2011E3

a. For all three cases, the path of integration when applying Ampere's Law is a circle concentric with the cylinder and perpendicular to its axis, with a radius r in the range specified

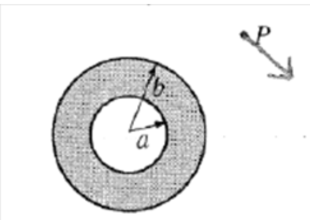
$\oint \vec{B} \cdot \vec{dl} = \mu_0 i_{enc}$

i. $I_{enc} = 0$ so $B = 0$

ii. $J = I_0/(\pi b^2 - \pi a^2)$ so $I_{enc} = J \times$ (area enclosed) $= I_0(r^2 - a^2)/(b^2 - a^2)$ giving $B = \mu_0 I_0(r^2 - a^2)/2\pi r(b^2 - a^2)$

iii. $B(2\pi 2b) = \mu_0 I_0$ gives $B = \mu_0 I_0/4\pi b$

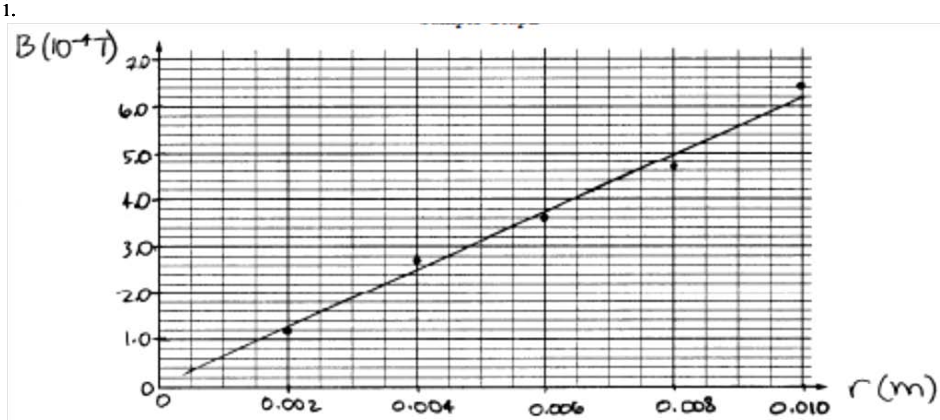
b.



Cross-sectional View
(current into page)

c. There are no forces on the electron (v = 0)

d. i.



ii. slope = $\Delta B/\Delta r = (6.2 \times 10^{-4}\ T - 2.8 \times 10^{-4}\ T)/(0.01\ m - 0.0045\ m) = 0.062$ T/m

from $B = \mu_0 I_0 r/2\pi b^2$ we get the slope as $\mu_0 I_0/2\pi b^2 = 0.062$ T/m giving $\mu_0 = 1.56 \times 10^{-6}$ (T-m)/A

SECTION C – Induction and Inductance

1975E3

a. From RHR (Ampere) the field through the loop points into the page. This flux is increasing so the induced current will create a field out of the page to oppose this increase. From RHR (solenoid) this current will then be counterclockwise

b.

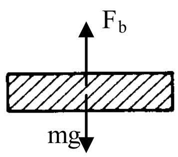
$$\phi = \int B\,dA = \int_a^b \frac{\mu_0 I}{2\pi r} l\,dr = \frac{\mu_0 I l}{2\pi}\int_a^b \frac{dr}{r} = \frac{\mu_0 I l}{2\pi}\ln\left(\frac{b}{a}\right)$$

$$|\mathcal{E}| = -\frac{d\phi}{dt} = -\frac{\mu_0 l}{2\pi}\ln\left(\frac{b}{a}\right)\frac{dI}{dt}$$

$$I = \frac{\mathcal{E}}{R} = -\frac{\mu_0 l}{2\pi R}\ln\left(\frac{b}{a}\right)\frac{dI}{dt}$$

1976E2

a.



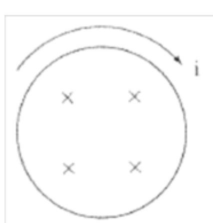
b. Since the bar falls at constant velocity $F_{net} = 0$ so … $mg = F_b$ … $mg = BIL$ … $I = mg / BL$

c. Simply use the formula $\mathcal{E} = BLv_o$

d. Using $V = IR$ … $BLv_o = (mg / BL)(R)$ … $R = B^2L^2v_o / mg$

1978E2

a.



b. From RHR (force) at every point the force is outward so the loop will tend to expand

c. $\mathcal{E} = -d\phi/dt = -A\,dB/dt = \alpha AB_0e^{-\alpha t}$

$Q = \int I dt = \int(\mathcal{E}/R)dt = (\alpha AB_0/R)\int e^{-\alpha t}\,dt = AB_0/R$ (integrate from zero to infinity)

d. $P = \int \mathcal{E}^2/R\,dt = (A^2\alpha^2B_0^2/R)\int e^{-2\alpha t}\,dt = A^2B_0^2\alpha/2R$

1980E3

a. The induced current will be clockwise. The field is increasing out of the page, the induced field must be into the page. By RHR (solenoid) the current will be clockwise.

b. $\mathcal{E} = -d\phi/dt$ where $\phi = BA$ and $A = \pi r^2$ so $\mathcal{E} = -\pi r^2 C$ and $I = \mathcal{E}/R = -\pi r^2 C/R$

c. The line integral of the electric field around a closed path is related to the changing flux by the expression

$$\oint E \cdot dl = -\frac{d\phi_B}{dt}$$

$$E 2\pi r = \pi r^2 C \ (r < a)$$

$$E = \frac{rC}{2}$$

d. for $r > a$, $d\phi/dt = \pi a^2 C$ so $E = a^2 C/2r$

1981E3

a. The field is decreasing out of the page, the induced field must be out of the page. By RHR (solenoid) the current will be counterclockwise.

b. $\mathcal{E} = -d\phi/dt = -B\, dA/dt = -B\, d/dt\, (s \times (s - x)) = Bsv$ (or just use motional emf $\mathcal{E} = BLv = Bsv$)

c. $I = \mathcal{E}/R = Bsv/R$

d. $P = I^2R = B^2s^2v^2/R$

1982E2

a.

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 i_{enc}$$

Applied to a circular path or radius r gives $B(2\pi r) = \mu_0 I$ so that $B = \mu_0 I/2\pi r$

b.

$$\phi = \int B\, dA = \int_a^{a+b} \frac{\mu_0 I}{2\pi r} l\, dr = \frac{\mu_0 I l}{2\pi} \int_a^{a+b} \frac{dr}{r} = \frac{\mu_0 I l}{2\pi} \ln\left(\frac{a+b}{a}\right)$$

c. i. At $t = \pi/\omega$ the field produced from the current in the long wire is changing from out of the page to into the page so the induced current must cause a field to be produced out of the page, and by RHR (solenoid) the induced current must be counterclockwise.

ii.

$$\phi = \frac{\mu_0 i_m l}{2\pi} \ln\left(\frac{a+b}{a}\right) \sin \omega t$$

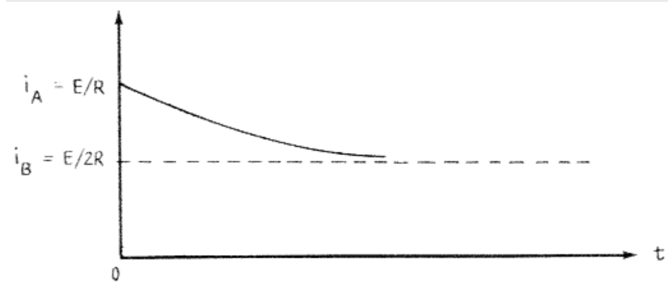
$$-\frac{d\phi}{dt} = -\frac{\mu_0 l}{2\pi} \ln \frac{a+b}{b}\ \omega i_m \cos \omega t$$

At $t = \pi/\omega$, $\cos \omega t = -1$ so

$$\mathcal{E} = \frac{\mu_0 l \omega i_m}{2\pi} \ln \frac{a+b}{b}$$

1982E3

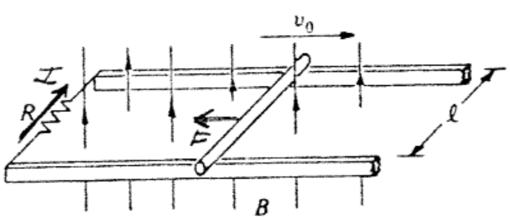
a. After the switch has been closed for a long time, the current will have ceased changing, so the inductor voltage $V_L = L(dI/dt) = 0$. Therefore the inductor can be ignored in this part of the problem and $i = \mathcal{E}/R$
b. After the switch has been opened, there are two resistors in series and $i_B = \mathcal{E}/2R$
c.



d. $\mathcal{E} = V_R + V_L$ and $V_R = 2Ri$ and $V_L = L(di/dt)$
$\mathcal{E} = 2Ri + L(di/dt)$
e. The expression involves the exponential form $e^{-t/\tau}$ where $\tau = L/2R$ and must satisfy the boundary conditions $i(0) = \mathcal{E}/R$ and $i(\infty) = \mathcal{E}/2R$, by reasoning $i(t) = (\mathcal{E}/2R)(1 + e^{-2Rt/L})$

1984E3

a. and c.



b. Motional emf $\mathcal{E} = Blv_0$ so $I = \mathcal{E}/R = Blv_0/R$
d. $F = ILB = B^2l^2v_0/R$
e.

$$P = Fv = \frac{B^2l^2}{R}\left(v_0 e^{-\frac{B^2l^2t}{mR}}\right)^2 = \frac{B^2l^2}{R}v_0{}^2 e^{-\frac{2B^2l^2t}{mR}}$$

f. $W = \int P dt$ and integrating the power expression from zero to infinity yields $\frac{1}{2} mv_0{}^2$

1985E3

a. $|\mathcal{E}| = d\phi/dt = A\ dB/dt = \pi r^2\ dB/dt = \pi(0.5\text{ m})^2(60\text{ T/s}) = 47\text{ V}$
b. E points to the left and $\mathcal{E} = Ed$ (for a uniform E field) which gives $E = \mathcal{E}/d = \mathcal{E}/2\pi r = 15$ V/m
c. $F = mv^2/r = qvB$ which gives $v = qrB/m = 8.8 \times 10^6$ m/s
d. $F = ma = qE$ where $E = 15$ V/m so $a = qE/m = 2.6 \times 10^{12}$ m/s^2

1986E2

a. $V = IR$ and the total resistance from the two 40 Ω branches in parallel is 20 Ω so $R_{total} = 25\ \Omega$
   $I_T = V/R_{total} = 1$ A, which will divide evenly between the two branches so $I = 0.5$ A
b. After the capacitor is charged, no current flows through the capacitor and the circuit behaves as it did without the capacitor so $I = 0.5$ A
c. Using Kirchhoff's Loop Rule, $V_C = 10$ V and $Q = CV = 100\ \mu C$
d. Now the circuit can be treated as a 10Ω/30Ω parallel combination in series with another 10Ω/30Ω parallel combination making $R_{total} = 5\ \Omega + 2 \times (10\ \Omega)(30\ \Omega)/(10\ \Omega + 30\ \Omega) = 20\ \Omega$ so $I_{total} = V/R_{total} = 1.25$ A and resistor R receives ¾ $I_{total} = 0.9375$ A
e. Using Kirchoff's junction rule, $I_L = I_R - I_{30} = 0.625$ A

1986E3

a.
$$\oint \vec{B} \cdot \overrightarrow{dl} = \mu_0 i_{enc}$$
   Where $i_{enc} = ct$ so $B = \mu_0 ct/2\pi r$
b. The field from the long wire by RHR (ampere) is into the page and increasing, the induced field must be out of the page. By RHR (solenoid) the current will be counterclockwise
c.
$$\phi = \int B\, dA = \int_a^{a+b} \frac{\mu_0 I}{2\pi r} b\, dr = \frac{\mu_0 Ib}{2\pi} \int_a^{a+b} \frac{dr}{r} = \frac{\mu_0 ctb}{2\pi} \ln\left(\frac{a+b}{a}\right)$$
$$I = \frac{1}{R}\frac{d\phi}{dt} = \frac{\mu_0 cb}{2\pi R} \ln\left(\frac{a+b}{a}\right)$$
d. The force is away from the wire as the repulsion of the (closer) oppositely directed current is greater than the attraction of the parallel (farther) current.
e. $F_{net} = ILB_a - ILB_{a+b}$ gives
$$F_{net} = \frac{\mu_0{}^2 c^2 b^2 t}{4\pi^2 R} \ln\left(\frac{a+b}{a}\right)\left(\frac{1}{a} - \frac{1}{a+b}\right)$$

1987E2

a. $\phi = BA = 2e^{-4t} \times 0.09 = 0.18e^{-4t}$
b. The field is decreasing out of the page, the induced field must be out of the page. By RHR (solenoid) the current will be counterclockwise
c. $\mathcal{E} = -d\phi/dt = 0.72e^{-4t}$
   $I = \mathcal{E}/R = 0.12e^{-4t}$
d. $W = \int P\, dt$ where $P = I^2R$ and the integral is from zero to infinity
   $W = \int 0.864e^{-8t} = 0.108$ J

1987E3

a. Immediately after the switch is closed, there is no current in the inductor so $I = \mathcal{E}/R_{total}$ = 20 V/200 Ω = 0.2 A
V_{90} = IR = 18 V

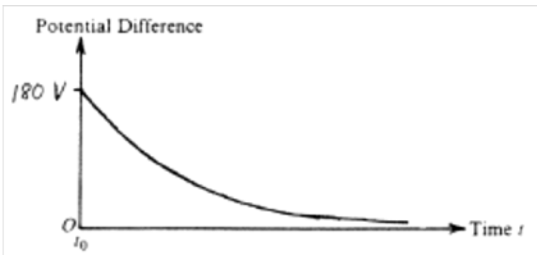
b. $\mathcal{E}$ = –LdI/dt and since the inductor is in parallel with the 90 Ω resistor, V_L = 18 V = –LdI/dt giving dI/dt = 36 A/s

c. After a long time, the inductor shorts the 90 Ω resistor so I = $\mathcal{E}$/10Ω = 2 A

d. $U_L = \frac{1}{2} LI^2$ = 1 J

e. Immediately after the switch is opened, the current in the inductor is the same as it was just before the switch was opened and it is still in parallel with the 90 Ω resistor so $V_{90} = V_L$ = IR = (2 A)(90 Ω) = 180 V

f.



1988E3

a.

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 i_{enc}$$

$$\int_a^b \vec{B} \cdot \vec{dl} + \int_b^c \vec{B} \cdot \vec{dl} + \int_c^d \vec{B} \cdot \vec{dl} + \int_d^a \vec{B} \cdot \vec{dl} = Bh + 0 + 0 + 0 = nhi$$

$$B = \mu_0 ni$$

b. $\phi = B\pi r_2^2$ and $\mathcal{E} = d\phi/dt = \pi r_2^2 dB/dt = \pi r_2^2 \mu_0 ni/t$

c. $\mathcal{E} = \int E\,dl = E\,2\pi r_2$ giving $E = \mu_0 n i r_2/2t$

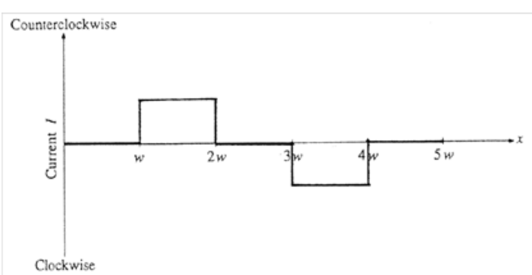
d. $\mathcal{E} = d\phi/dt = \pi r_1^2 dB/dt = \pi r_1^2 \mu_0 ni/t$

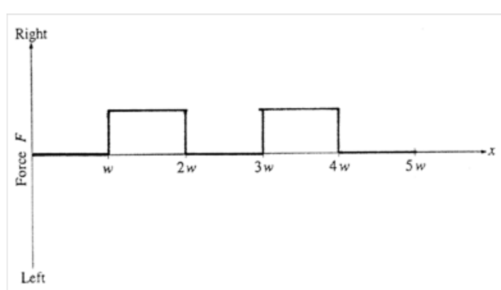
e. $\mathcal{E} = \int E\,dl = E\,2\pi r_3$ giving $E = \mu_0 n i r_1^2/2t r_3$

1989E2

a. i. Motional emf $\mathcal{E}$ = Bhv and I = $\mathcal{E}$/R = Bhv/R
ii. $F_A = F_B = ILB = B^2h^2v/R$

b. i. and ii.



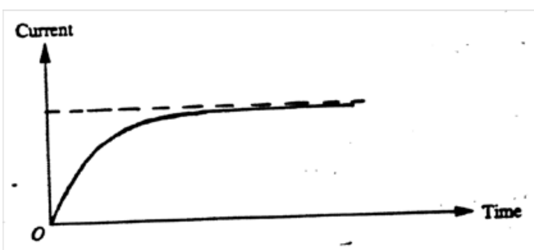


1990E3

a. Since the loop is at rest, the magnetic force upwards must counteract the gravitational force down. Based on the RHR, the current must flow to the right in the top part of the loop to make a magnetic force upwards so the current flow is CW.
b. $Mg = F_b$ … $Mg = BIL$ … $I = Mg / BL$
c. $V = IR$ $V = MgR / BL$
d. Simply use the formula $\mathcal{E} = BLv$
e. The batteries current flows to the right in the top bar as determined before. As the bar moves upwards, the induced emf would produce a current flowing to the left in the top bar based on Lenz law. These two effects oppose each other and the actual emf produced would be the difference between them.
$V_{net} = (V_{battery} - \mathcal{E}_{induced}) = MgR / BL - BLv$. The current is then found with V=IR. $I = Mg/BL - BLv/R$
f. Since the box moves at a constant speed, the new gravity force due to the new mass $(M - \Delta m)$ must equal the magnetic force in the top bar due to the current and field. The current flowing is that found in part e.
$F_g = F_b$ $(M-\Delta m)g = BIL$ $Mg - \Delta mg = B(Mg/BL - BLv/R)L$ $Mg - \Delta mg = Mg - B^2L^2v / R$
$\Delta m = B^2L^2v / Rg$

1991E2

a. The inductor prevents any sudden changes in current so I = 0
b. In steady state conditions, we ignore the inductor $I = \mathcal{E}/R_{total} = (50\text{ V})/(150\ \Omega + 100\ \Omega) = 0.2\text{ A}$
c.



d. $U_L = ½ LI^2 = 0.02$ J
e. Since the current will not change abruptly, it remains 0.2 A
f. $V_L = IR = (0.2\text{ A})(150\ \Omega) = 30\text{ V}$
g. Dissipated in the resistor (becomes thermal energy)

1991E3

a. Motional emf $\mathcal{E} = Blv_0$
b. $I = \mathcal{E}/R$ and $F = IlB$ gives $F = B^2l^2v_0/R$
c. $a = F/m = B^2l^2v_0/Rm$ and points opposite the direction of the velocity so

$$\frac{dv}{dt} = -v\frac{B^2l^2}{mR}$$

$$\int_{v_0}^{v}\frac{dv}{v} = -\int_0^t \frac{B^2l^2}{mR}dt$$

$$\ln v|_{v_0}^{v} = -\frac{B^2l^2}{mR}t$$

$$\ln\frac{v}{v_0} = -\frac{B^2 l^2}{mR} t$$

$$v = v_0 e^{-\frac{B^2 l^2 t}{mR}}$$

d. From energy conservation, the resistor will eventually dissipate all the kinetic energy from the rod
$E_{diss} = ½ mv_0^2$

1992E3

a. From RHR (Ampere) the field is directed out of the page

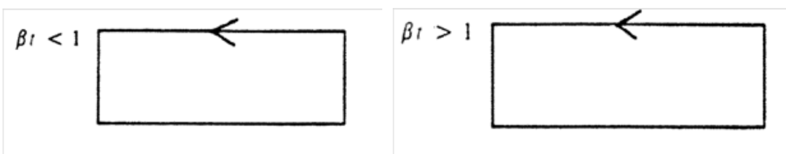
b. i.

$$\phi = \int B\,dA = \int_a^b \frac{\mu_0 I}{2\pi r} c\,dr = \frac{\mu_0 \alpha(1-\beta t)c}{2\pi}\int_a^b \frac{dr}{r} = \frac{\mu_0 \alpha(1-\beta t)c}{2\pi}\ln\left(\frac{b}{a}\right)$$

ii.

$$|\mathcal{E}| = -\frac{d\phi}{dt} = -\frac{\mu_0 \alpha c}{2\pi}\ln\left(\frac{b}{a}\right)(-\beta) = \frac{\mu_0 \alpha c \beta}{2\pi}\ln\left(\frac{b}{a}\right)$$

c.



When βt < 1 the field is decreasing out of the page, the induced current will then create a field out of the page
When βt > 1 the field is increasing into the page, the induced current will then create a field out of the page

d. The net force is down since the forces all pull outward on the loop and the bottom of the loop is closer to the wire

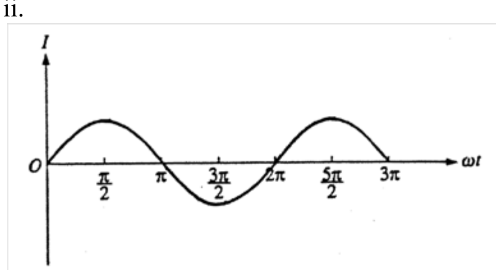
---

1993E2

a. i. $\phi = BA = abB_0$
ii. $\mathcal{E} = -d\phi/dt = 0$
iii. With no $\mathcal{E}$ and no current, there is no force

b. When $\omega t = \pi/2$, B = zero, the field has been decreasing and is about to change direction, the induced current will create a field into the page to oppose this change and by RHR (solenoid) will be clockwise

c. i. $\phi = abB_0 \cos \omega t$
$\mathcal{E} = -d\phi/dt = ab\omega B_0 \sin \omega t$ and $I = \mathcal{E}/R = (ab\omega B_0/R) \sin \omega t$
ii.



d. The maximum is when $\sin \omega t = 1$ so $I_{max} = ab\omega B_0/R$

1994E2

a. i. Consider the wire as a tube full of charges and focus on a single charge in the tube. That single charge is moving to the right in a B field pointing into the page. Using the RHR, that charge is pushed up to the satellite so the shuttle side is negative.
   ii. Induced emf is given by $\mathcal{E}$ = BLv = (3.3×10^{-5})(20000m)(7600) = 5016 V
b. V = IR   5016 = I (10000)   I = 0.5016 A
c. i. F_b = BIL = (3.3×10^{-5}) (0.5016)(20000) F_b = 0.331 N
   ii. The current flows up, away from the shuttle as indicated. Using the RHR for the given I and B gives the force direction on the wire pointing left which is opposite of the shuttles velocity.
d. $\Delta U = Pt$ where $P = I^2R$ so $\Delta U = I^2Rt = (0.5016\text{ A})^2(10{,}000\ \Omega)(7\text{ d})(24\text{ h/d})(60\text{ min/h})(60\text{ s/min}) = 1.52 \times 10^9$ J
e. The direction of the magnetic force would be reversed, this would do work on the shuttle, and the resulting gain in energy would increase the radius of the orbit

---

1995E3

a. Motional emf $\mathcal{E} = Bhv_0$
b. $I = \mathcal{E}/R = BHv_0/R$
c. The field is increasing out of the page, the induced field must be into the page. By RHR (solenoid) the current will be clockwise
d. $a = F/m = IHB/m = B^2H^2v/Rm$ and points opposite the direction of the velocity so

$$\frac{dv}{dt} = -v\frac{B^2H^2}{mR}$$

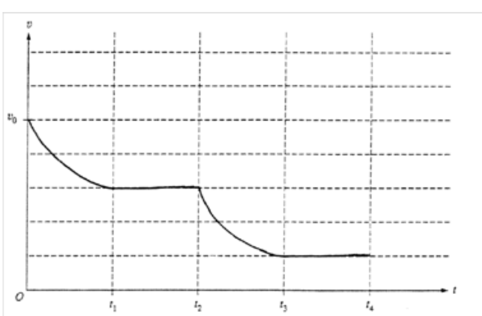
$$\int_{v_0}^{v}\frac{dv}{v} = -\int_0^t \frac{B^2H^2}{mR}dt$$

$$\ln v|_{v_0}^{v} = -\frac{B^2H^2}{mR}t$$

$$\ln\frac{v}{v_0} = -\frac{B^2H^2}{mR}t$$

$$v = v_0e^{-\frac{B^2H^2t}{mR}}$$

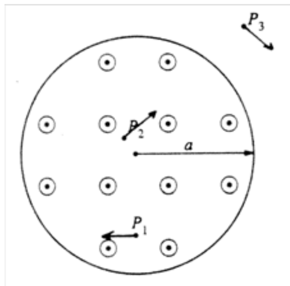
e.



1996E3

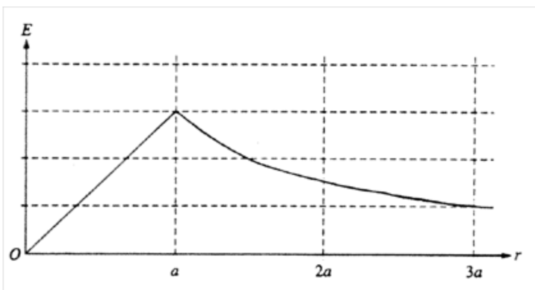
a. $\phi = B\pi r^2$ and $\mathcal{E} = d\phi/dt = \pi r^2 dB/dt$
$\mathcal{E} = \int E\, dl = E\, 2\pi r$ giving $E = (r/2)dB/dt$

b.



c. The calculation is the same as part (a) except the contributing flux exists only inside radius a
$E(2\pi r) = \pi a^2\, dB/dt$
$E = (a^2/2r)\, dB/dt$

d.



1997E3

a.
$$\oint \vec{B} \cdot \vec{dl} = \mu_0 i_{enc}$$
Applied to a circular path or radius r gives $B(2\pi r) = \mu_0 I$ so that $B = \mu_0 I/2\pi r$

b. By RHR (Ampere) the field points out of the page, in the +z direction

c.
$$\phi = \int B\, dA = \int_s^{s+w} \frac{\mu_0 I}{2\pi r} l\, dr = \frac{\mu_0 Il}{2\pi}\int_s^{s+w}\frac{dr}{r} = \frac{\mu_0 Il}{2\pi}\ln r\Big|_s^{s+w} = \frac{\mu_0 Il}{2\pi}(\ln(s+w) - \ln(s))$$
$$= \frac{\mu_0 Il}{2\pi}\ln\left(\frac{s+w}{s}\right)$$

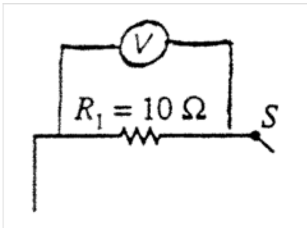
d. As the loop moves away, the field decreases (out of the page) so the induced current will create a field out of the page to oppose this change and by RHR (solenoid) the current is counterclockwise

e. –y, the closer section of the loop experiences the larger force toward the wire

f.
$$|\mathcal{E}| = -\frac{d\phi}{dt} = -\frac{d}{dt}\frac{\mu_0 Il}{2\pi}(\ln(s+w) - \ln(s)) = -\frac{\mu_0 Il}{2\pi}\left(\frac{1}{s+w} - \frac{1}{s}\right)\frac{ds}{dt} = \frac{\mu_0 Ilv}{2\pi R}\left(\frac{w}{s(s+w)}\right)$$

1998E2

a.



b. The capacitor is ignored: $I = \mathcal{E}/(R_1 + R_2) = 20\ V/30\ \Omega = 0.67\ A$
$V = IR = 6.67\ V$

c. i. V = 0 (the capacitor is charged, current is zero.
ii. $Q = CV = (15\ \mu F)(20\ V) = 300\ \mu C$

d. V = 0

e. i. The inductor is ignored: $I = \mathcal{E}/(R_1 + R_2) = 20\ V/30\ \Omega = 0.67\ A$
ii. $U_L = \frac{1}{2} LI^2 = 0.444\ J$

f. $\mathcal{E} - I(R_1 + R_2) - L(dI/dt) = 0$

1998E3

a. At constant speed $F_{net} = 0$ $F_b = F_{gx}$ $BIL = mg \sin \theta$ $I = mg \sin \theta / BL$

b. Using the induced emf and equating to V=IR we have IR = BLv, sub in I from above
$(mg \sin \theta / BL)R = BLv$ … solve for $v = mgR \sin \theta / B^2L^2$

c. Rate of energy is power. $P = I^2R$ $P = (mg \sin \theta / BL)^2 R$

d. Since the resistor is placed between the rails at the bottom, it is now in parallel with the top resistor because the current has two pathways to chose, the top loop with resistor R or the new bottom loop with the new resistor R. This effectively decreases the total resistance of the circuit. Based on the formula found in part b, lower resistance equates to less velocity.

e. Yes, the speed will decrease. With two resistors in parallel, the effective resistance decreases and v is proportional to R

1999E2

a. $|\mathcal{E}| = d\phi/dt = A\ dB/dt = \pi r^2\ dB/dt = \pi(0.6\ m)^2(0.40\ T/s) = 0.45\ V$

b. $I = \mathcal{E}/R = 0.09\ A$

c. $W = Pt = I^2Rt = 0.61\ J$

d. The brightness would be less, since the effective area for the magnetic flux is less, the induced current will be less

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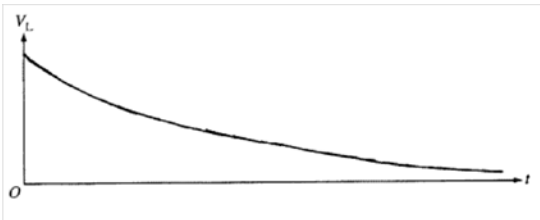
2000E1

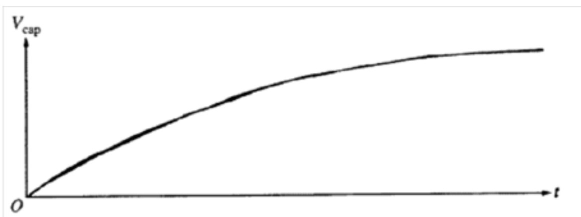
a. A, C, B
Bulb A receives the total current (it is in the main branch), then the current divides where bulb C receives more current while having the same voltage as bulb B

b. i. Immediately after the switch is closed, there is no current in the inductor so $I_C = 0$ and the circuit consists of resistors A and B only and $I_A = I_B = E/R_{total} = (42\text{ V})/(10\ \Omega + 12\ \Omega) = 1.91\text{ A}$
ii. A long time later, the potential difference across the inductor is zero so the circuit behaves as it did in part (a). The total resistance is $R_{total} = R_A + (R_B)(R_C)/(R_B + R_C) = 14\ \Omega$ so $I_{total} = I_A = (42\text{ V})/(14\ \Omega) = 3\text{A}$
$I_B = 1/3\ I_{total} = 1\text{ A}$ and $I_C = 2/3\ I_{total} = 2\text{ A}$

c.



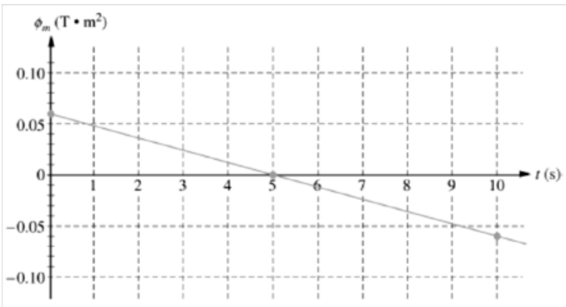
d.



2002E3

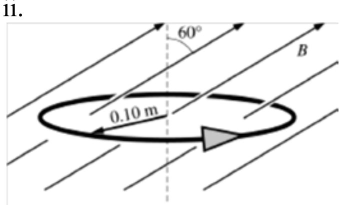
a. $\phi = BA\cos\theta$ where $A = \pi r^2$ and $\theta = 60^\circ$
$\phi = \pi(0.10\text{ m})^2(4(1 - 0.2t))\cos 60^\circ = (0.063)(1 - 0.2t)$ Wb

b.



c. $\mathcal{E} = -d\phi/dt = -(0.063)(-0.2) = 0.013$ V

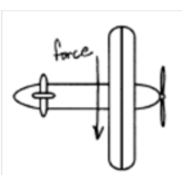
d. i. $I = \mathcal{E}/R = 2.6 \times 10^{-4}$ A
ii.



e. $W = Pt = I\mathcal{E}t = 1.3 \times 10^{-5}$ J

2003E3

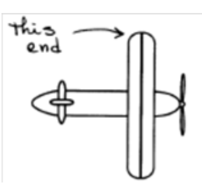
a.



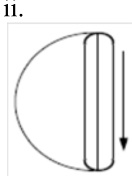
b. Equilibrium is reached when the electric force due to the separation of charge in the antenna balances the magnetic force on an electron, that is $qE = qvB\sin\theta$ giving $E = vB\sin\theta = 0.0037$ V/m

c. $V = Ed = 0.0553$ V

d.



e. i. There must be a change in the magnetic flux through the closed loop. To do this the plane could execute a forward dive increasing its angle with respect to the horizontal
ii.



2004E3

a.

$$\phi = \int B\,dA = \int_l^{4l} \frac{\mu_0 I}{2\pi r} 4l\,dr = \frac{2\mu_0 Il}{\pi}\int_l^{4l}\frac{dr}{r} = \frac{2\mu_0 Il}{\pi}\ln\left(\frac{4l}{l}\right) = \frac{2\mu_0 Il}{\pi}\ln 4$$

b. The field is decreasing out of the page, the induced field must be out of the page. By RHR (solenoid) the current will be counterclockwise

c. $\phi = 2l\mu_0 I_0(\ln 4)e^{-kt}/\pi$ and $\mathcal{E} = -d\phi/dt$ and $I_{loop} = \mathcal{E}/R$ which gives $I_{loop} = 2lk\mu_0 I_0(\ln 4)e^{-kt}/\pi R$

d. $P = I^2R$ and $W = \int P\,dt$ (from zero to infinity) which gives $W = (2l\mu_0 I_0(\ln 4)/\pi)^2(k/2R)$

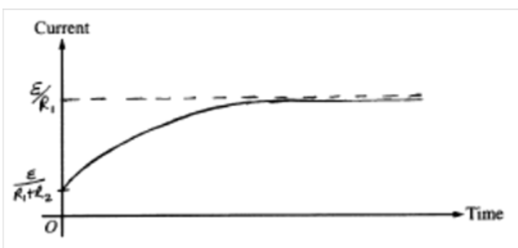
2005E2

a. The current through the inductor is zero immediately after the switch is closed. So $R_{total} = R_1 + R_2$ and $I = \mathcal{E}/R_{total} = \mathcal{E}/(R_1 + R_2)$

b. Since the inductor is in parallel with R_2 its voltage is identical so $V_L = V_{R2} = IR_2 = LdI/dt$
$dI/dt = IR_2/L = \mathcal{E}R_2/(R_1 + R_2)L$

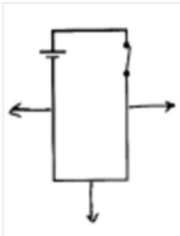
c. After a long time the inductor shorts R_2 so $R_{total} = R_1$ and $I = \mathcal{E}/R_1$

d.



2006E3

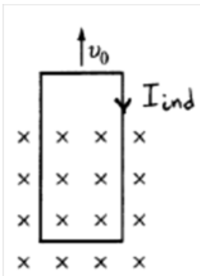
a.



b. $F_S = F_B$

$kx = ILB$ so $B_0 = kx/Iw$

c. i.



ii. Motional emf $\mathcal{E} = B_0wv_0$ and $I = \mathcal{E}/R = B_0wv_0/R$

d. $P = I^2R = B_0^2w^2v_0^2/R$

e. Increases. F is proportional to B as is the current.

2007E3

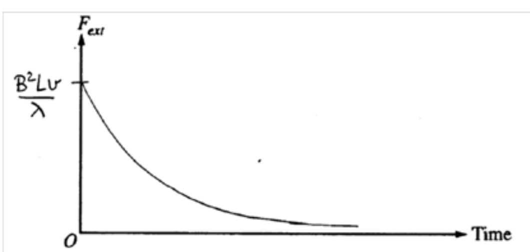
a. The flux is increasing into the page, the induced field must be out of the page. By RHR (solenoid) the current will be counterclockwise

b. Motional emf $\mathcal{E} = Blv$ and the resistance depends on the length $R = \lambda d = \lambda(L + 2x)$ where $x = vt$

$I = \mathcal{E}/R = BLv/\lambda(L + 2vt)$

c. $F = ILB = B^2L^2v/\lambda(L + 2vt)$

d.

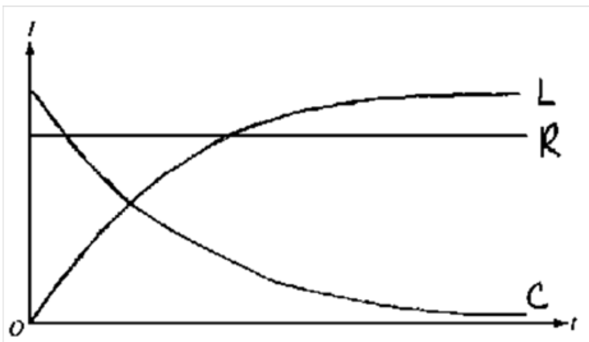


e. Decreases. If $F_{ext} = 0$, then the only force is F_B which opposes the motion of the rod.

2008E2

a. i. For the parallel branch $1/R = 1/(100\ \Omega + 50\ \Omega) + 1/300\ \Omega$ which gives $R = 100\ \Omega$ and with the main branch resistor $R_{total} = 300\ \Omega$ and $I_{total} = \mathcal{E}/R_{total} = 5$ A
$V_1 = I_{total}R_1 = 1000$ V and $V_2 = \mathcal{E} - V_1 = 500$ V
ii. The current in branch 3 is zero at t = 0 so $R_{total} = 500\ \Omega$ and $I_{total} = 3$ A so $V_2 = IR_2 = 900$ V
iii. The capacitor is ignored at t = 0 so $R_{total} = 200\ \Omega + (1/100\ \Omega + 1/300\ \Omega)^{-1} = 275\ \Omega$ and $I_{total} = 5.45$ A
$V_2 = I_{total}R_{parallel\ branches} = (5.45\text{ A})(75\ \Omega) = 410$ V

b.

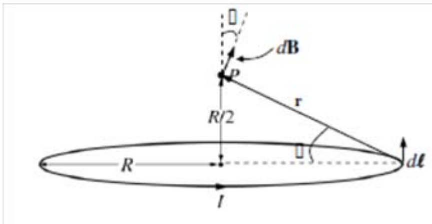


The current is constant with the resistor placed between points *A* and *B*. The resistance of that branch is more than when the capacitor and inductor are placed there, so the current will be less. The inductor initially opposes the flow of current, so the initial current in that branch is zero. Eventually, the inductor acts like a wire and does not impede the flow of charge, as the rate of change of current decreases to zero. Initially, the capacitor is uncharged and current is a maximum in the branch containing R_3. As the capacitor charges the current in that branch decreases to zero.

2008E3

a. i. B points toward the top of the page

ii.



The empty rectangle in the diagram represents the angle α

$$dB = \frac{\mu_0}{4\pi}\frac{I\,dl \times r}{r^3} = \frac{\mu_0}{4\pi}\frac{I\,dl\,r\sin\theta}{r^3} = \frac{\mu_0}{4\pi}\frac{I\,dl}{r^2}$$
$$B = \int dB_{vertical} = \int dB\cos\alpha = \int \frac{R}{r}\,dB$$
$$r = \sqrt{R^2 + \frac{R^2}{4}} = \frac{\sqrt{5}}{2}R$$
$$B = \int \frac{R}{r}\,dB = \frac{\mu_0 IR}{4\pi\left(\frac{\sqrt{5}}{2}R\right)^3}\int dl = \frac{\mu_0 IR}{4\pi\left(\frac{\sqrt{5}}{2}R\right)^3}2\pi R = \frac{4\mu_0 I}{5\sqrt{5}R}$$

b. B_{net} is the vector sum from the two loops, which produce identical fields in the same direction so $B_{net} = 2B_1$

$$B_{net} = \frac{8\mu_0 I}{5\sqrt{5}R}$$

c. $\phi = BA = B_{net}s^2$

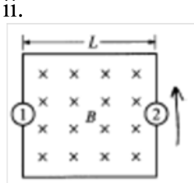
d. $\phi = B_{net}s^2\cos\theta = B_{net}s^2\cos\omega t$ and $\mathcal{E} = -d\phi/dt = -B_{net}s^2\omega\sin\omega t$

2009E3

a. $|\mathcal{E}| = d\phi/dt = A(dB/dt) = L^2 a$

b. i. The resistors are in series so $R_t = 2R_0$ and $I = \mathcal{E}/R = aL^2/2R_0$

ii.



c. $P = I^2R = a^2L^4/4R_0$

d. Bulb 1 is brighter. The emf is the same as in the original circuit (since there is no flux through the added loop). Adding a bulb in parallel with bulb 2 decreases the overall resistance of the circuit. Decreasing the overall resistance increases the overall current, which is equal to the current in bulb 1

e. Bulb 1 is the same brightness. Since each loop has half the area, each has half the original emf. But each also has half the resistance. This means the current and thus the power in bulb 1 is the same. The two loops are essentially identical. Separately, the flux through each loop would create an emf that is counterclockwise. Since these emfs are in opposite directions in the central wire, the net effect is that there is no emf in that wire. Therefore the situation is equivalent to the original one.

2010E3

a. The flux is decreasing out of the page, the induced field must be out of the page. By RHR (solenoid) the current will be counterclockwise

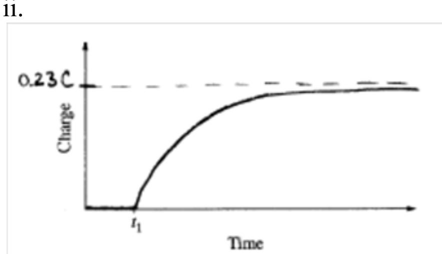
b. Remains the same. The field and the flux both vary linearly with time. The emf, which is the time derivative of the flux, must then be constant. Since the power output of the lightbulb depends only on the emf and resistance (which are both constant), the power must be constant.

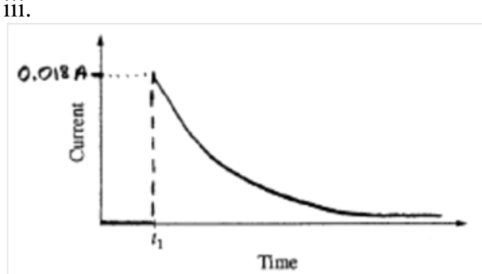
c.
$$\oint \vec{B} \cdot \vec{dl} = \mu_0 i_{enc}$$
Applied to a circular path or radius r gives $B(2\pi r) = \mu_0 I_0$ so that $B = \mu_0 I_0/2\pi r$

d.
$$\phi = \int B\, dA = \int_d^{a+d} \frac{\mu_0 I}{2\pi r} b\, dr = \frac{\mu_0 I b}{2\pi} \int_d^{a+d} \frac{dr}{r} = \frac{\mu_0 (I_0 - Kt) b}{2\pi} \ln\left(\frac{a+d}{d}\right)$$

e. $\mathcal{E} = -d\phi/dt = -(\mu_0 b/2\pi)\ln[(a + d)/d](-K)$
$P = \mathcal{E}^2/R = (1/R)\{(\mu_0 bK/2\pi)\ln[(a + d)/d]\}^2$

2011E2

a. i. $Q = CV = (25 \times 10^{-3}\ \text{F})(9\ \text{V}) = 0.23\ \text{C}$
ii.


iii.


b. i. $U_C = ½\, Q^2/C = 0.22$ J
ii. The maximum current is when there is no charge in the capacitor and all the energy is stored in the inductor
$0.22\ \text{J} = U_L = ½\, LI^2$ which gives $I_{max} = 0.3$ A
iii. From the loop rule: $L\,dI/dt + Q/C = 0$ so $dI/dt = -Q/CL = -(50 \times 10^{-3}\ \text{C})/(25 \times 10^{-3}\ \text{F})(5.0\ \text{H}) = -0.4$ A/s

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