MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DEPARTMENT OF PHYSICS

Physics 8.022 ***Fall 2000***

8.022 Electricity and Magnetism

Quiz #2

2:05-3:35 PM, Monday, Nov. 13, 2000
Room 4-370

There are four problems worth a total of 100 points.
Answer all problems

This is a closed book quiz. No notes are allowed.
Calculators are not necessary.

In each problem, justify your answer.
Solutions with insufficient explanations will not be given full credit.

Useful Formulas

Resistors: $I=\int_S \vec{J}\cdot d\vec{a};\ \vec{J}=\sigma\vec{E};\ V=IR;\ P=VI=I^2R=\frac{V^2}{R}$

Capacitors: $Q=CV;\ \ U=\frac{1}{2}CV^2=\frac{1}{2}\frac{Q^2}{C}$

$$\vec{\nabla}\cdot\vec{E}=4\pi\rho \qquad \vec{\nabla}\times\vec{E}=-\frac{1}{c}\frac{\partial\vec{B}}{\partial t} \qquad \vec{\nabla}\cdot\vec{B}=0 \qquad \vec{\nabla}\times\vec{B}=\frac{4\pi}{c}\vec{J}$$

$$\int_S \vec{E}\cdot d\vec{a}=4\pi Q_{encl} \quad \oint_C \vec{E}\cdot d\vec{s}=-\frac{1}{c}\frac{d\Phi_B}{dt} \quad \int_S \vec{B}\cdot d\vec{a}=0 \quad \oint_C \vec{B}\cdot d\vec{s}=\frac{4\pi}{c}I_{encl}$$

Cyclotron motion: $\omega=\frac{qB}{\gamma mc}\quad R=\frac{mv}{qB}$ Biot-Savart Law : $d\vec{B}=\frac{Id\vec{l}\times\hat{r}}{cr^2}$

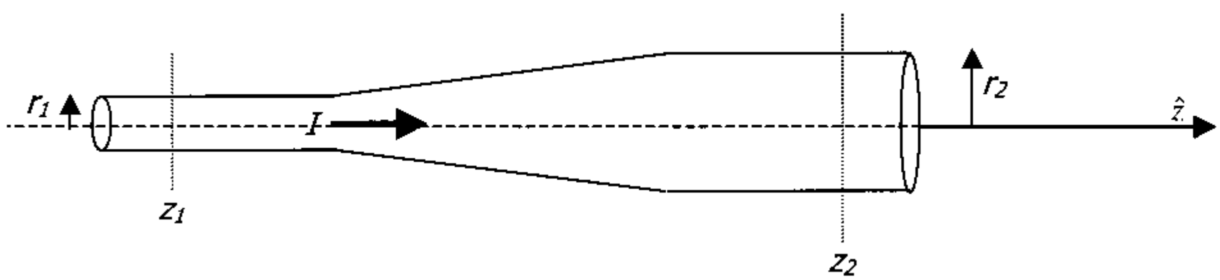
Lorentz Force: $\vec{F}=\vec{E}+q\frac{\vec{v}}{c}\times\vec{B}$

Transformation of fields: $\vec{E}'_\perp=\gamma\vec{E}_\perp+\gamma\vec{\beta}\times\vec{B}_\perp \quad \vec{E}'_\parallel=\vec{E}_\parallel$
$\vec{B}'_\perp=\gamma\vec{B}_\perp-\gamma\vec{\beta}\times\vec{E}_\perp \quad \vec{B}'_\parallel=\vec{B}_\parallel$

Lorentz trans. $x'=\gamma x-\gamma\beta ct \quad p'=\gamma p-\gamma\beta E/c$; $t'=\gamma t-\gamma\beta x/c \quad E'=\gamma E-\beta\gamma cp$ where $\beta=v/c$, $\gamma=1/\sqrt{1-\beta^2}$

Problem 1

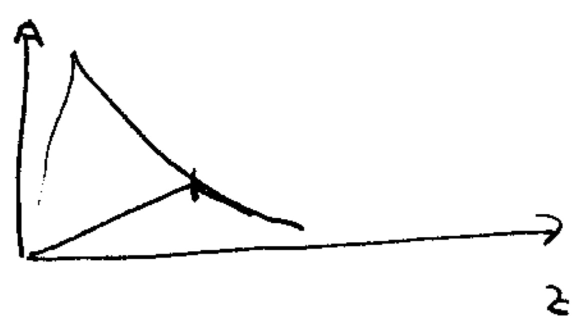
A current I flows in a wire which changes from radius r_1 to radius r_2 as shown below. The current density $\vec{J}$ inside the wire is uniform: $\vec{J} = \vec{J}(z)$. z_1 and z_2 are far from the place where the wire changes radius. Be sure to clearly state all assumptions and clearly state any symmetry arguments.



a) Find the current density $\vec{J}$ at z_1 and z_2 in terms of r_1, r_2, I, z_1 and z_2 and/or constants.

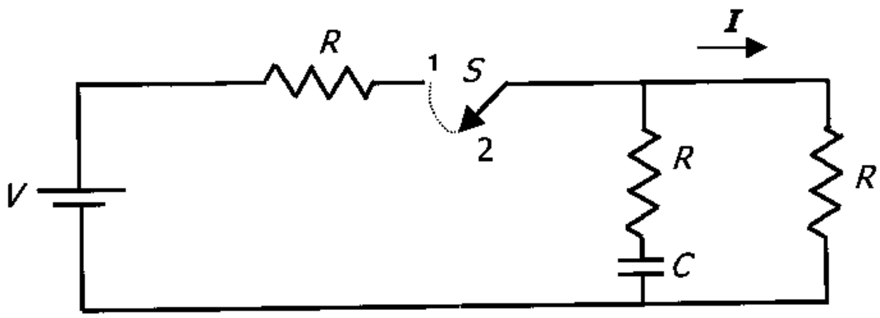
b) Find the magnetic field $\vec{B}$ at z_1 and z_2 both inside and outside of the wire in terms of r_1, r_2, I, z_1 and z_2 and/or constants.

c) One the same plot, sketch the magnetic field $\vec{B}(z_1, r)$ and $\vec{B}(z_2, r)$ as functions of r. Label the maximum value of the field in each case.



Problem 2

A circuit is connected as shown. At before $t=0$, the switch is in position 1 for a long time. At $t=0$, the switch S is moved to position 2 as shown.



a) Find the charge on the capacitor at $t=0$, $Q(0)$ in terms of V, C and/or R and constants.

b) Find the current at $t=0$ after the switch is moved to position 2, $I(0)$ in terms of V, C and/or R and constants.

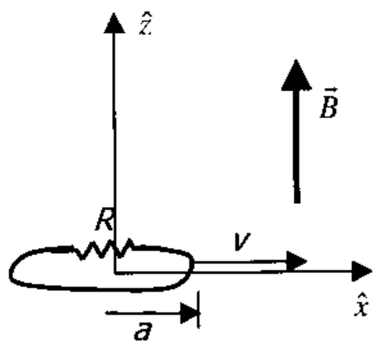
c) Find the current at $t>0$ after the switch is moved to position 2, $I(t)$ in terms of V, C, t and/or R and constants.

d) Find the energy U stored in the capacitor at $t=0$ in terms of V, C and/or R and constants.

e) Give the power dissipation $P(t)$ in the resistors and find the total energy dissipated $U = \int_0^\infty P(t)dt$ in terms of V, C, t and/or R and constants in each case.

Problem 3

A loop of mass *m*, radius *a* and area *A* with a resistor *R* moves with velocity $\vec{v} = v\hat{x}$ in a magnetic field $\vec{B} = B_o\left(\frac{x}{l}\right)\hat{z}$. *l>>a*, i.e. you may assume the magnetic field is constant over the area of the loop at any given time. At *t=0*, the loop is located at the origin.



a) Find the flux Φ through the loop at a function of position along the *x* axis in terms of *x, B₀, R, v, a, m* and/or A and constants.

b) Find the EMF $E(v)$ around the loop as a function of the velocity *v* in terms of x, B_o, R, v, a, l, m and/or A and constants.

c) Find the current flowing in the loop $I(v)$ as function of velocity *v*. Clearly indicate the direction of current flow. Use the results of the previous part to compute the power dissipated in the resistor *P(v)* as a function of the velocity in terms of x, B_o, R, v, a, l, m and/or A and constants.

d) Compute the kinetic energy of the loop as a function of time, *E(t)* in terms of x, B_o, R, v, a, l, t, m and/or A and constants . In performing the integration, remember $E = \frac{1}{2}mv^2$.

e) How far does the loop travel from the origin before it stops? How long does it take? Give your answer in terms of in terms of x, B_o, R, v, a, l, m and/or A and constants.

Problem 4

A particle of mass *m* and charge *q* is at rest in frame *F* at *t=0* in a constant applied electric field $\vec{E} = E_o\hat{x}$ and applied magnetic field $\vec{B} = B_o\hat{y}$ $E_o < B_o$. The particle is also viewed by an observer in frame *F′* moving with velocity $\vec{v}$ relative to *F*.

a) What must the direction of $\vec{v}$ be in order for there to be no applied electric field in frame *F*?

b) Find $\vec{v}$ such that there is no applied electric field in *F′* in terms of *m, q,* E_o and/or B_o and constants.

c) Find the magnetic field $\vec{B}'$ measured in *F′* in terms of *m, q,* E_o and/or B_o and constants.

d) Find the force acting on the particle $\vec{F}$ as measured by an observer in *F* in terms of *m, q,* E_o and/or B_o and constants.

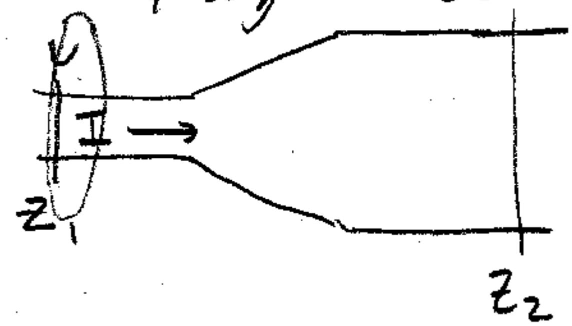
e) Find the force acting on the particle $\vec{F}'$ as measured by an observer in *F′*. Show this is consistent with your answer for part d). Give your answer in terms of *m, q,* E_o and/or B_o and constants.

Note: In the statement of the problem, "applied" refers to all fields **except the field created by the point charge *q*.**

Peter Fisher
13 Nov. 2020

Quiz #2 Solution

#1 a)



$$\vec{J} = \frac{I}{2\pi r_1^2}\,\hat{z} = \vec{J}(z_1) \qquad \vec{J}(z_2) = \frac{I}{2\pi r_2^2}\,\hat{z}$$

b) at $z = z_1$: $\vec{B}(z_1) = B(z_1)\,\hat{\phi}$ - azimuthal symmetry

Ampère Law: $2\pi r\, B = \frac{4\pi}{c} J \pi r^2$ if $r < r_1$

$$B = \frac{2}{c}\left(\frac{I}{r_1^2}\right) r$$

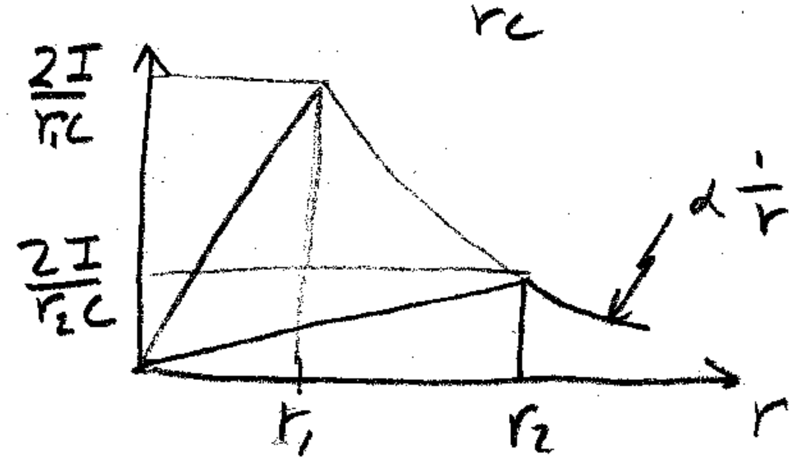
$r > r_1$:

$$B = \frac{2I}{rc}$$

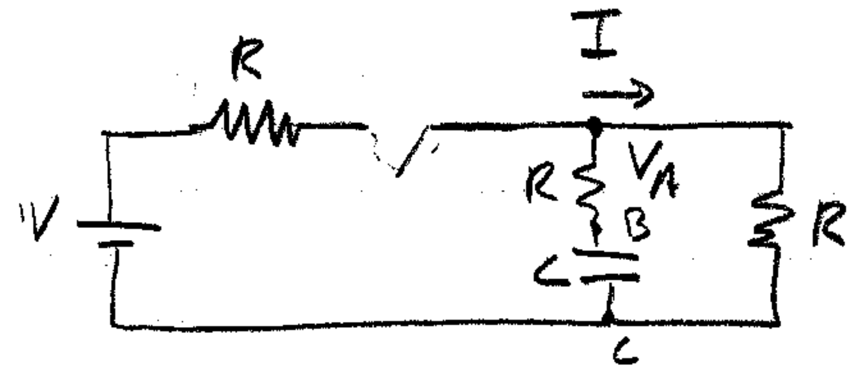
at $z = z_2$: $B = \frac{2I}{c r_2}\frac{r}{r_2}$ $\qquad r < r_2$

$$= \frac{2I}{rc} \qquad r > r_2$$

c)



2.



a) at $t<0$, switch has been closed for a long time.

$$I(t) = \frac{V}{2R} \; ; \quad V_A = \frac{V}{2} = \frac{Q}{C}$$

$$\Rightarrow Q(t) = \frac{VC}{2}$$

b) at $t=0$, $V_{BC} = \frac{VC}{2} \Rightarrow I = \frac{V_{BC}}{2R} = \frac{V}{4R}$

c) $I = -\dot{Q}$ $\quad V_{BC} = \frac{Q}{C} \Rightarrow -\dot{Q} = \frac{Q}{2RC} = -\frac{dQ}{dt}$

$$\frac{dQ}{Q} = -\frac{dt}{2RC} \Rightarrow Q(t) = Q(0)\, e^{-t/2RC}$$

$$= \frac{VC}{2} e^{-t/2RC}$$

d) at $t=0$, energy in Capacitor is

$$U = \tfrac{1}{2} C V(0)^2 = \frac{1}{2} C \frac{V^2}{4} = \frac{CV^2}{8}$$

e) $I(t) = -\dot{Q} = -\frac{VC}{2} \; \frac{-1}{2RC} \; e^{-t/2RC}$

$$I(t) = \frac{V}{4R} e^{-t/RC2}$$

$$V(t) = \frac{Q}{C} = \frac{V}{2} e^{-t/2RC}$$

$$\Rightarrow P = \frac{V^2}{8R} e^{-t/RC}$$

$$U = \int_0^\infty \frac{V^2}{8R} e^{-t/RC} dt = -\frac{RCV^2}{8R} e^{-t/4RC}\Big|_0^\infty$$

$$= \frac{1}{8} CV^2$$

3 a) $\vec{B} = B\left(\frac{x}{L}\right)\hat{z}$

b) $\Phi = \frac{B \times A}{L}$ $\qquad \mathcal{E} = -\frac{1}{c}\frac{d\Phi}{dt}$

$$= -\frac{BAv}{cL}$$

c) $I = \frac{\mathcal{E}}{R} = \frac{BAv}{cLR}$ $\qquad$ Unit: $\frac{\frac{erg}{cm^3}\, cm^4\, \frac{cm^2}{s^2}}{\frac{cm^2}{s^2}\, cm^2\, \frac{s}{cm}}$ $\quad \frac{erg}{s}$ ✓

$$P = -IV = \frac{-B^2A^2v^2}{c^2L^2R} = \frac{dE}{dt} = \frac{d}{dt}\left(\frac{1}{2}mv^2\right)$$

$\alpha = \frac{B^2A^2}{c^2L^2R} \Rightarrow \frac{2\alpha}{m}E = \frac{dE}{dt}$

Unit
$\alpha = \frac{erg}{s}\cdot\frac{s^2}{cm^2} = g/s$

$$-\frac{2\alpha\, dt}{m} = \frac{dE}{E}$$

$\frac{cm^2}{s^2}\frac{g}{s}\cdot\frac{g^2}{cm^2}$

$\Rightarrow E(t) = E_0\, e^{-2\alpha t/m}$ ✓ $\qquad \frac{erg}{s}\cdot\frac{s^2}{cm^2}\cdot\frac{s}{g}$

$$v = \sqrt{\frac{2E}{m}} = v_0\, e^{-\alpha t/m}$$

d) $r = \int_0^\infty v\, dt = -\frac{v_0 m}{\alpha}\, e^{-\alpha t/m}\Big|_0^\infty$

$= \frac{vm}{\alpha}$ $\qquad \frac{cm}{s}\cdot g\cdot\frac{s}{g}$ ✓

4 a) $\vec{E}'_\perp = \gamma \vec{E}_\perp + \gamma \vec{\beta} \times \vec{B}_\perp$

$\vec{E}_\parallel{}' = \vec{E}_\parallel \Rightarrow \vec{E}_\parallel = 0$

Must be $\perp$ to $\hat{x}$ and $\hat{y} \Rightarrow \hat{z}$

b) Take $\vec{v} = v\hat{z}$

$\vec{E}'_\perp = 0 = \cancel{\gamma} E_0 \hat{x} + \cancel{\gamma} \frac{v}{c} \hat{z} \times B_0 \hat{y}$ $\quad \hat{z} \times \hat{y} = -\hat{x}$

$0 = E_0 \hat{x} - \frac{v B_0}{c} \hat{x}$

$\Rightarrow \quad v = \frac{c E_0}{B_0}$

c) $\vec{B}'_\perp = \gamma B_0 \hat{y} - \gamma \frac{v}{c} \hat{z} \times E_0 \hat{x}$

$= \left(\gamma B_0 - \gamma \frac{c E_0^2}{c B_0}\right) \hat{y} = \gamma B_0 (1 - \beta^2)$

$= B_0 \sqrt{1 - \beta^2} = B_0 \sqrt{1 - \frac{E_0^2}{B_0^2}}$

d) In F: $\quad \vec{F} = q E_0 \hat{x}$

e) In F': $\quad \vec{F} = q \frac{\vec{v}' \times \vec{B}'}{c} = -q \frac{E_0}{B_0} \overbrace{(\hat{z} \times \hat{y})}^{-\hat{x}} \frac{B_0}{\gamma}$

$\vec{v}' = -v\hat{z}$

$= +\frac{q E_0}{\gamma B_0} \hat{x}$

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DEPARTMENT OF PHYSICS

Physics 8.022 *Fall 1995*

8.022 Electricity and Magnetism

Quiz #2

2:05-3:35 pm, Wednesday November 8, 1995
Room 6-120

There are four problems worth a total of 100 points.
Answer all problems

This is a closed book quiz. No notes are allowed.
Calculators are not necessary.

In each problem, justify your answer.
Solutions with insufficient explanations will not be given full credit.

Useful Formulas

Resistors: $I = \int_S \vec{J} \cdot d\vec{a};\ \vec{J} = \sigma \vec{E};\ V = IR;\ P = VI = I^2 R = \frac{V^2}{R}$

Capacitors: $Q = CV;\ \ U = \frac{1}{2} C V^2 = \frac{1}{2} \frac{Q^2}{C}$

Inductors: $V = L \frac{dI}{dt};\ \ U = \frac{1}{2} L I^2$

$$\vec{\nabla} \cdot \vec{E} = 4\pi\rho \qquad \vec{\nabla} \times \vec{E} = -\frac{1}{c}\frac{\partial \vec{B}}{\partial t} \qquad \vec{\nabla} \cdot \vec{B} = 0 \qquad \vec{\nabla} \times \vec{B} = \frac{4\pi}{c} \vec{J}$$

$$\int_S \vec{E} \cdot d\vec{a} = 4\pi Q_{encl} \quad \oint_C \vec{E} \cdot d\vec{s} = -\frac{1}{c}\frac{d\Phi_B}{dt} \quad \int_S \vec{B} \cdot d\vec{a} = 0 \quad \oint_C \vec{B} \cdot d\vec{s} = \frac{4\pi}{c} I_{encl}$$

$$U = \int_V \left(\frac{E^2}{8\pi} + \frac{B^2}{8\pi} \right) dV$$

Cyclotron motion: $\omega = \frac{qB}{\gamma m c} \quad R = \frac{mv}{qB}$

Biot-Savart Law : $d\vec{B} = \frac{I d\vec{l} \times \hat{r}}{c r^2}$

Lorentz Force: $\vec{F} = q \frac{\vec{v}}{c} \times \vec{B}$

[1] (20 Points)

During a supernova collapse in a distance galaxy, a photon (which is massless) and a particle of mass m are emitted simultaneously in the same direction. Both travel a distance l to earth where both are detected. The detector on earth detects the massive particle a time t after the photon.

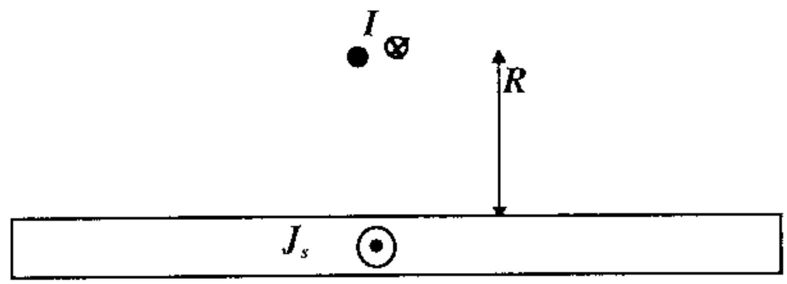
(a) What is the travel time of the photon as measured by an observer on earth?

(b) What is the travel time of the massive particle as determined by an observer on earth?

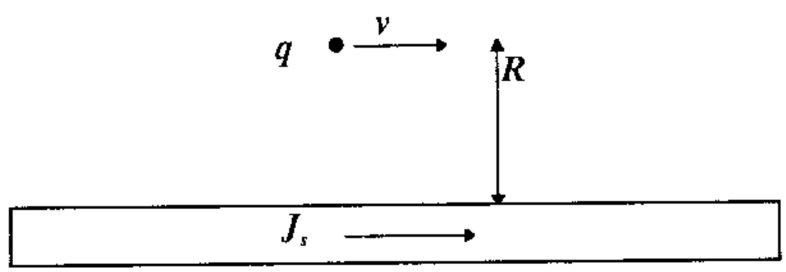
(c) What is the velocity v of the massive particle as determined by an observer on earth?

(d) What is the travel time of the massive particle as determined by an observer in a frame in which the massive particle is at rest?

[2] (25 Points)



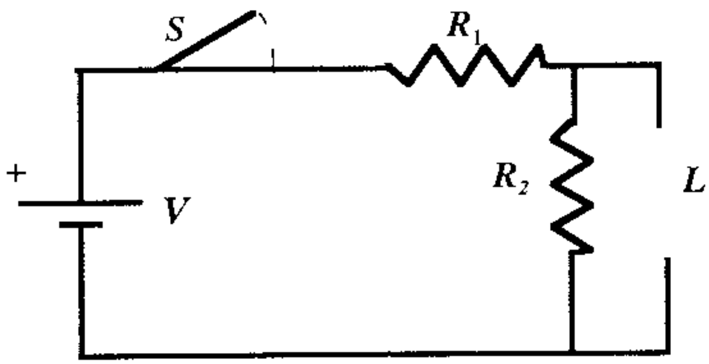
(a) An infinite wire carrying current I is suspended a distance R above an infinite surface current J_s as shown above. What force per unit length acts on the wire? Assume the current in the wire does not change the surface current J_s.



(b) The wire is replaced by a particle of charge q traveling parallel to the direction of the surface current. Initially, the charge is distance R from the surface current. What is the direction and magnitude of the force acting on q?

(c) Take $J_s = \dfrac{mvc^2}{2\pi qR}$. Sketch the trajectory of the charged particle over enough of an interval to show its long term behavior. Assume that crossing the surface current has no influence on the trajectory of the particle or the surface current.

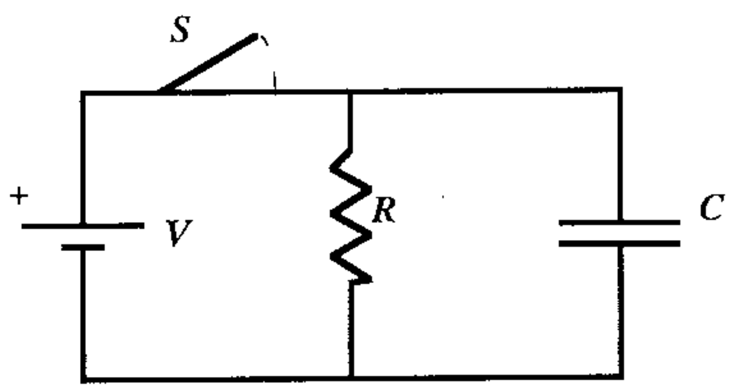
[3] (25 Points)



(a) The circuit shown above initially has switch *S* closed and all currents have come to a constant values (i.e. the switch was closed a long time in the past). Give the values of the current in all parts of the circuit. Make a clearly labeled drawing.

(b) At $t=0$, the switch is opened. What is the current through resistor R_2 for $t>0$ as a function of t?

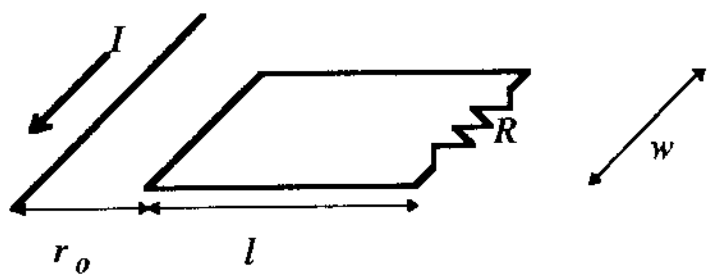
(c) Give the power dissipated by the current flowing through resistor R_2 for $t>0$. Integrate the power dissipation from $t=0$ to infinity to give the total energy dissipated by the circuit after the switch open. How does this compare with the total energy stored in the inductor at $t=0$?



(d) In the circuit above, what is the current through *R* long after the switch *S* has been closed?

(e) At $t=0$, the switch is opened. Give the current through *R* as a function of time and the total power dissipated through *R*. Compare with the total energy stored in the capacitor before the switch is opened.

[4] (30 Points)



A loop of conductor of length l and width w is located a distance r_o from an infinitely long wire carrying a current I. The conducting loop contains a resistor of resistance R, otherwise the conductor is ideal. In all parts below, assume the the magnetic field due to any current induced in the loop is negligible compared to the magnetic field from the wire.

(a) What is the magnetic flux through the loop?

(b) The current in the wire is increased at a constant rate such that $I(t) = I_o + At$. What is the induced electromotive force around the loop?

(c) Calculate the current I_{loop} flowing around the loop as the current increases at a constant rate as in part b. Indicate clearly the direction of current flow.

(d) Use the result of part (c) the magnitude and direction of the Lorentz force acting on each side of the loop. Make a sketch showing the direction of the force on each side of the loop. Give the magnitude and direction of the net force on the loop.

(e) The current in the wire is now fixed at I_o and the loop is moved *toward* the wire with velocity v. What is the electromotive force induced around the wire?

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DEPARTMENT OF PHYSICS

Physics 8.022 *Fall 1995*

8.022 Electricity and Magnetism

Quiz #2 Solutions

[1] (20 Points)

Identify the rest frame of the earth as the unprimed frame and the rest frame of the massive particle.

(a) The travel time of the photon is $t_\gamma = l / c$.

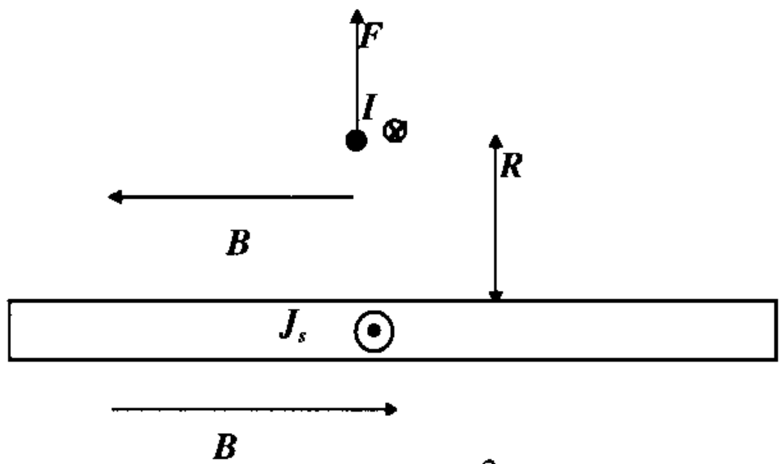
(b) The travel time of the massive particle is $t_m = t + l / c$ since it was emitted at the same time as the photon and arrived a time *t* after.

(c) The velocity of the massive particle is $v = \frac{l}{t_m} = \frac{c}{1 + {ct}/{l}}$ in the earth rest frame.

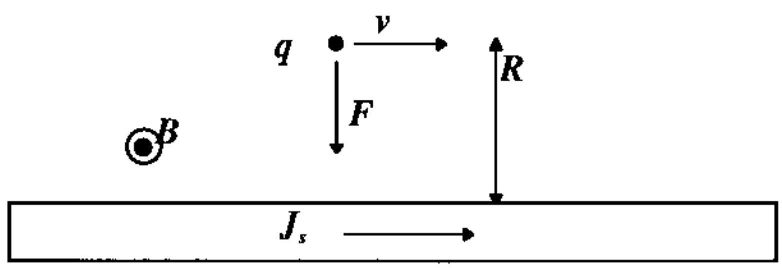
(d) The travel time of the particle in its rest frame is t_m'. The travel time observed from the earth frame is

$$t_m = t_m' \gamma \Rightarrow t_m' = t_m \sqrt{1 - \left(\frac{c}{1 + {ct}/{l}} \right)^2}$$

[2] (25 Points)

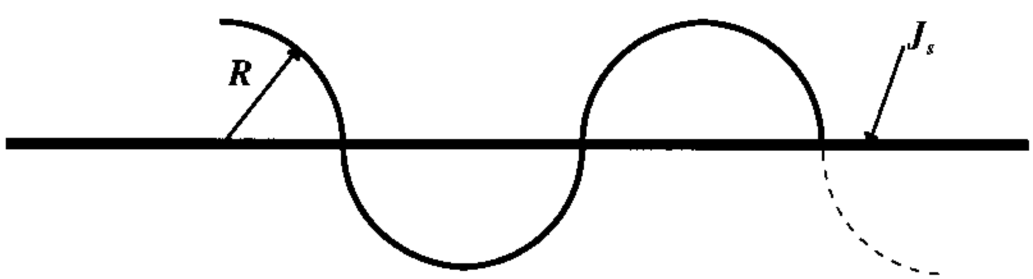


(a) The surface current generates a magnetic field $B = \frac{2\pi}{c} J_s$ as shown above. The force is given by the Lorentz force $\vec{F} = q\frac{\vec{v}}{c} \times \vec{B} \Rightarrow F/l = \frac{\overset{2}{\cancel{4}}\pi I J_s}{c^2}$ and the force points away from the surface current.



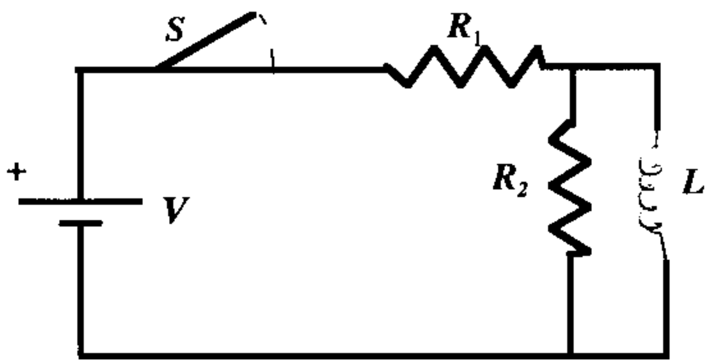
(b) The magnitude of the force is $F = q\frac{v}{c}B = \frac{\overset{2}{\cancel{4}}\pi v q}{c^2} J_s$ *toward* the sheet as shown.

(c) The initial velocity of the particle is perpendicular to the magnetic field and the magnitude of the field is constant. The particle will follow a circular orbit. For a circular orbit, the centripetal force is balanced by the central force $q\frac{v}{c}B = \frac{mv^2}{r} \Rightarrow r = \frac{mvc}{qB} = \frac{mvc}{q\left(\frac{2\pi}{c}J_s\right)} = R$. The particle will go a quarter of the way around the orbit and then cross the surface current, where the magnetic field change direction. It will then orbit in the opposite sense for a half orbit and so on:

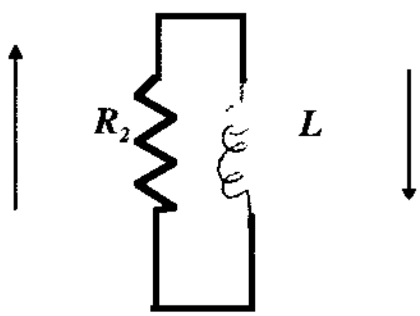


[3] (25 Points)

(a) The potential drop across the inductor is $-L\, dI/dt$, so long after the switch has been closed, the inductor acts like a short circuit (i.e. zero potential difference) across R_2. The total resistance is then R_1 and the current is just $I=V/R_1$ through R_1 and L and zero current flows through R_2.



(b) After the switch is open, the circuit looks like this:

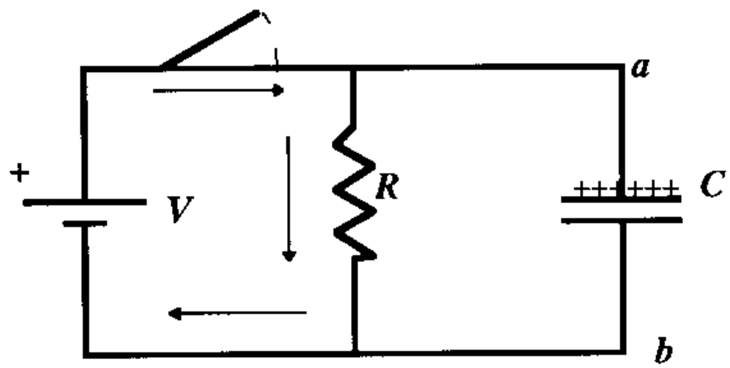


and at t=0, a current $I=V/R_1$ flows through R_2. as shown. Applying Kirkhoff's law around the loop gives $-IR_2 - L\frac{dI}{dt} = 0 \Rightarrow \frac{dI}{I} = -\frac{R_2 dt}{L} \Rightarrow \int \frac{dI}{I} = \ln I = -\frac{R_2 t}{L} + K$. At t=0, the current through the inductor is V/R_1, $\ln V/R_1 = K \Rightarrow I(t) = V/R_1\, e^{-\frac{R_2 t}{L}}$. The power dissipated through R_2 is

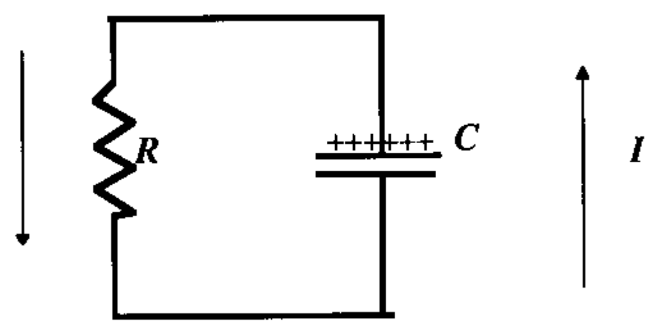
$$P(t) = I(t)^2 R_2 = R_2\left(\frac{V^2}{R_1^2}\right)e^{-\frac{R_2 t}{L}} \Rightarrow E = \int_0^\infty R_2\left(\frac{V^2}{R_1^2}\right)e^{-\frac{R_2 t}{L}}dt = \frac{LI(0)^2}{2}$$

which is just the energy stored in the inductor before the switch is opened.

[3] (continued)



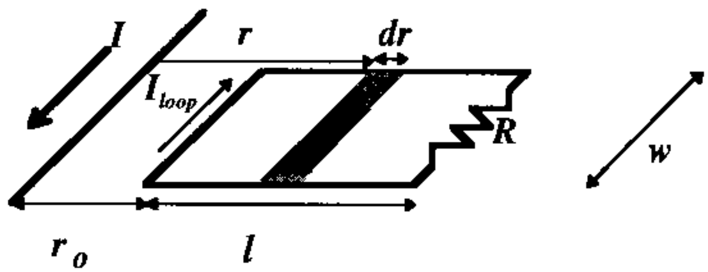
(d) The current flowing across the capacitor is zero; $Q = CV \Rightarrow I = C\,{}^{dV}\!/_{dt}$ and a long time after the switch is closed, all voltages have stopped changing and the capacitor appears to be an open circuit. All the current then flows through R and the total current is $I = {}^{V}\!/_{R}$.



(e) At t=0, the capacitor is charged with charge Q=CV, so the V_{ab}=V. Applying Kirkhoff's law around the loop gives $\frac{Q(t)}{C} + I(t)R = 0 \Rightarrow \frac{dQ}{dt} = -\frac{Q}{RC}$. The current has been defined so that $I = -{}^{dQ}\!/_{dt}$ where Q is the total charge on the resistor. Solving gives $Q(t) = CVe^{-t/RC} \Rightarrow I(t) = {}^{V}\!/_{R}e^{-t/RC}$The power dissipation is $P(t) = I^2R = {}^{V^2}\!/_{R}e^{-2t/RC}$. The total energy dissipated is

$E = \int_0^\infty \frac{V^2}{R}e^{-2t/RC}dt = \frac{V^2}{R}\left(\frac{RC}{-2}\right)e^{-2t/RC}\Big|_0^\infty = \frac{CV^2}{2}$. This is just the energy stored in the capacitor.

[4] (30 Points)

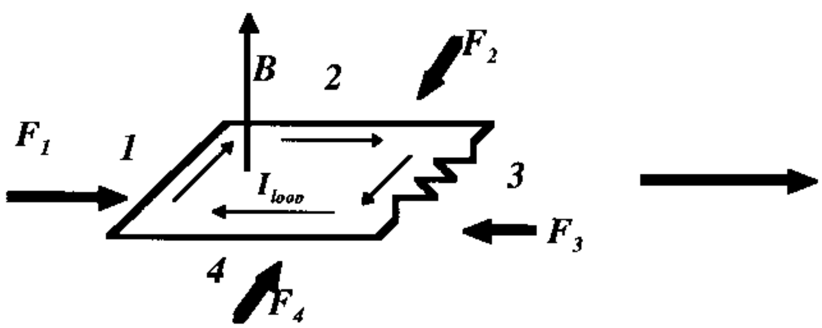


(a) The magnetic field from the current carrying wire I is $\vec{B}=\frac{2I}{rc}\hat{\phi}$. If we consider the amount of flux in a thin slice of the loop at r, we have $d\Phi=\vec{B}\cdot d\vec{a}=\frac{2I}{rc}wdr \Rightarrow \Phi=\frac{2I}{c}w\int_{r_o}^{r_o+l}\frac{dr}{r}=\frac{2Iw}{c}\ln\frac{r_o+l}{r_o}$.

(b) $\mathcal{E}=-\frac{1}{c}\frac{d\Phi}{dt}=-\frac{2Aw}{c^2}\ln\frac{r_o+l}{r_o}$

(c) The current is $I_{loop}=\mathcal{E}/R=-\frac{1}{c}\frac{d\Phi}{dt}=-\frac{2Aw}{c^2R}\ln\left(\frac{r_o+l}{r_o}\right)$ in the direction indicated.

(d)



For side 1, a little segment of length ds gives $d\vec{F}=dq\frac{\vec{v}}{c}\times\vec{B}$ for an incremental segment. The force is the same for each step is the same and $F_1=w\lambda\frac{v}{c}\frac{2I}{r_oc}=\frac{2Iw}{r_oc^2}I_{loop}=\frac{4IAw^2}{r_oc^4R}\ln\frac{r_o+l}{r_o}$ which points away from the wire. For side 3, $F_3=\frac{4IAw^2}{(r_o+l)c^4R}\ln\frac{r_o+l}{r_o}$. For side 2, increment ds gives $dF_2=\lambda ds\frac{v}{c}\frac{2I}{rc}=\frac{2II_{loop}}{rc^2}ds$ where the force points toward the center of the loop. Integrating gives $F_2=\frac{2II_{loop}}{c^2}\int_{r_o}^{r_o+l}\frac{dr}{r}=\frac{2II_{loop}}{c^2}\ln\frac{r_o+l}{r_o}$ and $\vec{F}_2=-\vec{F}_4$, so there is no net force from the sides. The net force is then $\vec{F}_{net} = \frac{2Iw}{c^2} I_{loop} \left(\frac{1}{r_o} - \frac{1}{r_o + l} \right) = \frac{2II_{loop}w}{c^2} \frac{l}{r_o(r_o + l)}$ pointing *away* from the wire. This is what we expect; from Lenz's law, the forces on the wire must act to try to reduce the flux through the wire.

(e) The flux through the wire is $\Phi = \frac{2Iw}{c} \ln \frac{r_o + l}{r_o} \Rightarrow \frac{d\Phi}{dt} = \frac{2Iw}{c} \frac{r_o}{r_o + l} \frac{d}{dt}\left(\frac{r_o + l}{r_o} \right)$. The loop is moving *toward* the wire, so $dr_o/dt = -v$ and $\frac{d\Phi}{dt} = \frac{2Iw}{c} \frac{r_o}{r_o + l} \frac{-r_o v + (r_o + l)v}{r_o^2} \Rightarrow \mathcal{E} = -\frac{2Iwlv}{c^2 r_o (r_o + l)}$.