MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Physics

8.02 **Fall 2007**

Turn in at your table during class labeled with your name and group (e.g. L02 12A)

Problem Set 8

Due: Wednesday, October 31st at class beginning (before 10:15/12:15)

This problem set focuses on material from classes 18-20 (week 8). Textbook references can be found at the top of the summaries from these three days.

Warm Up

Problem 1: Charges in a Uniform Field

An electron with velocity $v_x\hat{\mathbf{i}} + v_y\hat{\mathbf{j}}$ moves through a uniform magnetic field $B_x\hat{\mathbf{i}} + B_y\hat{\mathbf{j}}$

(a) Find the magnitude of the force on the electron.
(b) Repeat your calculation for a proton having the same velocity.

Problem 2: Power Line

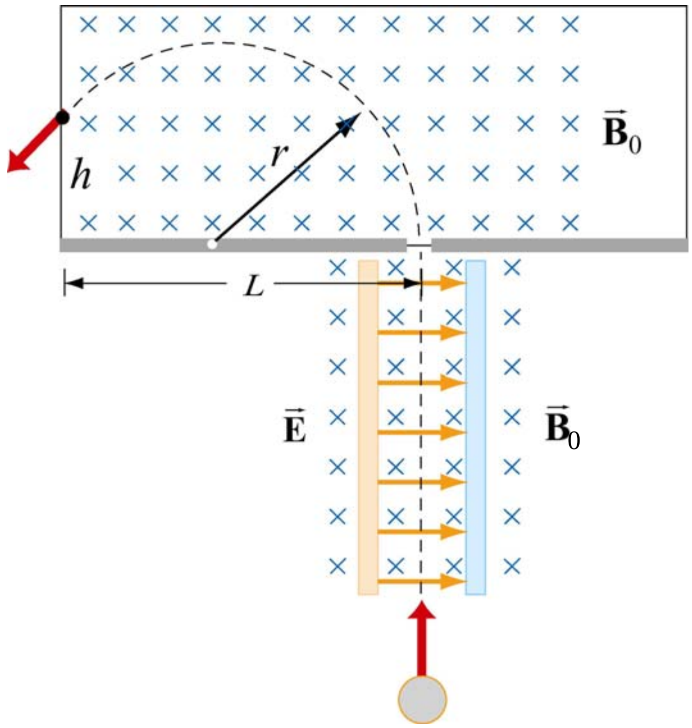
A horizontal power line carries a current of I from south to north. Earth's magnetic field (B_{Earth} = 62.1 μT) is directed toward the north and is inclined downward at an angle θ to the horizontal. Find the magnitude of the magnetic force on a length L of the line due to Earth's field. Please also calculate a value numerically for I = 3000 A, θ = 78.0º and L = 100 m, since it's useful to think about real world numbers.

Problem 3: Triangular Loop

A current loop, carrying a current I, is in the shape of a right triangle with sides 30, 40, and 50 cm. The loop is in a uniform magnetic field B whose direction is parallel to the current in the 50 cm side of the loop.

Find the magnitude of
(a) the magnetic dipole moment of the loop in amperes-square meters; and
(b) the torque on the loop.

<u>Exam Question</u>



Problem 4:
A Bainbridge mass spectrometer is shown in the figure. A charged particle with mass *m*, charge *q* and speed *V* enters from the bottom of the figure and traces out the trajectory shown in the fields shown. The magnetic field is everywhere $\mathbf{B}_0$ as pictured. The only electric field is in the region where the trajectory of the charge is a straight line.

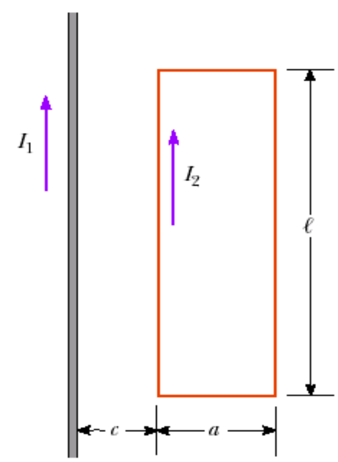
(a) Is the sign of the charge positive or negative? To get credit for your answer you must give a logical reason to justify it.

(b) What must the electric field have been set to in order to keep the particle moving in a straight line? Justify your answer.

(c) When the charge is moving through the second (curved) segment of its trajectory, *derive* a formula for the radius *r* of the arc through which it moves. To get credit for your answer, you must show the details of your derivation.

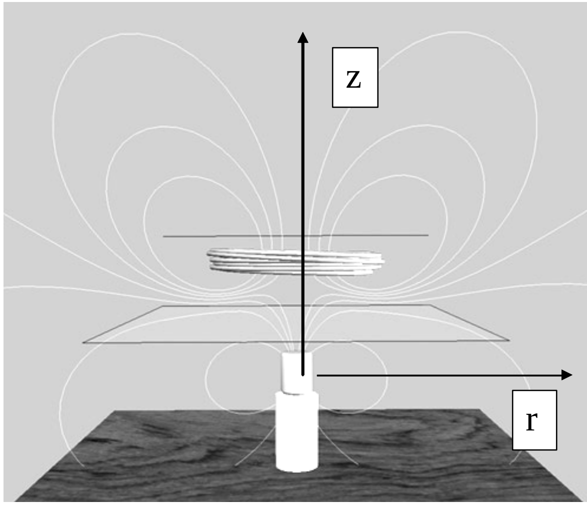
<u>Analytic Problems…</u>

Problem 5: Force on the Rectangular Loop



In the figure, the current in the long, straight wire is I_1 and the wire lies in the plane of the rectangular loop of length ℓ and width *a*, that carries the current I_2. The distance between the left side of the rectangular loop and the straight wire is *c*. Find the magnitude and direction of the net force exerted on the loop by the magnetic field created by the wire.

Problem 6: Levitating Coil



A coil of wire has radius R has N turns and total mass m. It sits on a platform a distance z above a magnetic dipole of dipole moment M_{dipole} (see sketch). The north pole of the dipole is on top. The coil is held down to the platform on which it sits by a clamp.

(a) Using a battery attached to the coil, you run a current I in the coil. Viewed from above, in what direction do you want the current in the coil to flow (clockwise or counterclockwise) so that the force on the coil has an upward component?

(b) Calculate the total magnetic force on the coil given that the magnetic field from a magnetic dipole with dipole moment M_{dipole} is given (in cylindrical coordinates) by:

$$\vec{\mathbf{B}}(r,z) = \frac{\mu_o M_{dipole}}{4\pi}\left[\hat{\mathbf{r}}\frac{3rz}{\left(r^2+z^2\right)^{5/2}} + \hat{\mathbf{k}}\frac{\left(2z^2-r^2\right)}{\left(r^2+z^2\right)^{5/2}}\right]$$

To see a grass seeds representation of this field, go to the Mapping Fields applet, go to the pull down *Examples* menu, and choose *Dipole in no field,*).

(c) If you release the clamp, the coil will move upwards as long as the current I it carries is greater than a certain amount. What is the minimum current I_{min} required for the coil to move upward when it is released?

(d) Take m = 20 g, M_{dipole} = 10 $\text{A}\cdot\text{m}^2$, g = 9.8 m/s^2, N = 30 turns, R = 50 mm and z=50 mm. What is the numerical value of I_{min} in part (c) above for these parameters?

You can see if you have the correct current by going to the Levitating Coil applet and inserting the numerical values of the current you calculated for this cases. In this applet, a positive value of the current means that the current in the coil is circulating ***counterclockwise*** as seen from above, and vice versa. The platform in the applet is at 50 mm, and we have put in a marker line at 100 mm. You can set the current in the coil at the value you want, and then hit play to see if the coil will levitate for that value of the current. We have some damping in the applet so that the coil will eventually settle down to a steady position for a given current after a bit.

Experiment 5: Faraday's Law

Problem 7: Calculating Flux from Current and Faraday's Law

In part 1 of this lab you will move a coil from well above to well below a strong permanent magnet. You will measure the current in the loop during this motion using a current sensor. The program will also display the flux "measured" through the loop, even though this value is never directly measured. In this problem you will understand how.

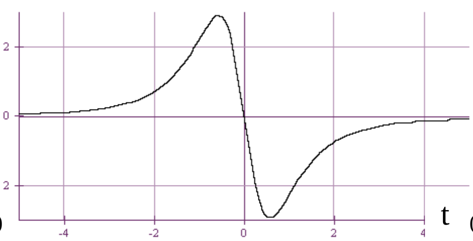
(a) Starting from Faraday's Law and Ohm's law, write an equation relating the current in the loop to the time derivative of the flux through the loop.

(b) Now integrate that expression to get the time dependence of the flux through the loop $\Phi(t)$ as a function of current $I(t)$. What assumption must the software make (what value must it arbitrarily set) before it can plot flux vs. time?

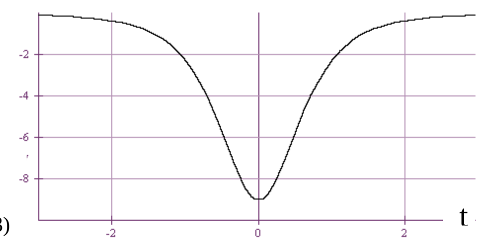
Problem 8: Predictions: Coil Moving Past Magnetic Dipole

In moving the coil over the magnet, measurements of current and flux for each of several motions will look like one of the below plots. For current, counter-clockwise when viewed from above is positive. For flux, upwards is positive. The north pole of the magnet is pointing up.

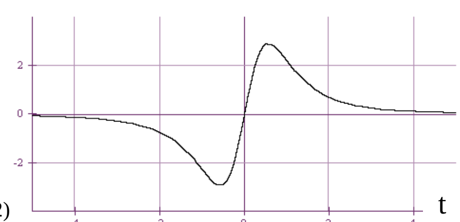
(1)



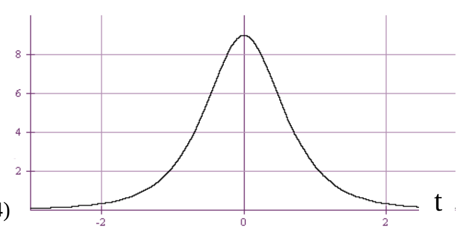
(3)



(2)



(4)



Suppose you move the loop from well *above* the magnet to well *below* the magnet at a constant speed. Which graph most closely resembles the graph of:

(a) *magnetic flux through the loop* as a function of time?

(b) *current through the loop* as a function of time?

Suppose you now move the loop from well *below* the magnet to well *above* the magnet at a constant speed. Which graph most closely resembles the graph of:

(c) *magnetic flux through the loop* as a function of time?

(d) *current through the loop* as a function of time?

Problem 9: Predictions: Force on Coil Moving Past Magnetic Dipole

In part 2 of this lab you will feel the force on a conducting loop as it moves past the magnet. For the following conditions, in what direction should the magnetic force point?

As you are moving the loop from well *above* the magnet to well *below* the magnet at a constant speed…
(a) … and the loop is *above* the magnet.
(b) … and the loop is *below* the magnet

As you are moving the loop from well *below* the magnet to well *above* the magnet at a constant speed…
(c) … and the loop is *below* the magnet.
(d) … and the loop is *above* the magnet

Make sure that you record your answers to the previous two problems asking for predictions as you will need them in the lab.

Problem 10: Feeling the Force

In part 2, rather than using the same coil we use in part 1, we will instead use an aluminum cylinder to "better feel" the force. To figure out why, answer the following.

a) If we were to double the number of turns in the coil how would the force change?

b) Using the result of (a), how should we think about the Al tube? Why do we "better feel" the force?

In case you are interested, the wire is copper, and of roughly the same diameter as the thickness of the aluminum cylinder, although this information won't necessarily help you in answering the question.