MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science

6.007 – Electromagnetic Energy: From Motors to Lasers
Spring 2011

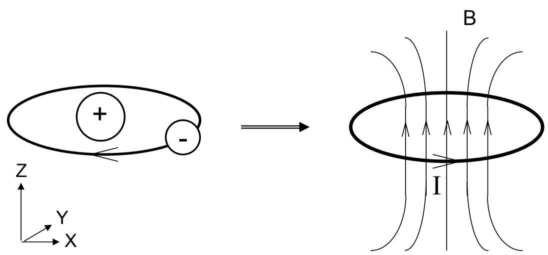
Problem Set 3: Magnetic Materials and Magnetic Circuits

Due Wednesday, February 23, 2011

The reading for this problem set is chapters 13, 14 and 16 from Shen and Kong.

Problem 3.1 –Magnetic Moments

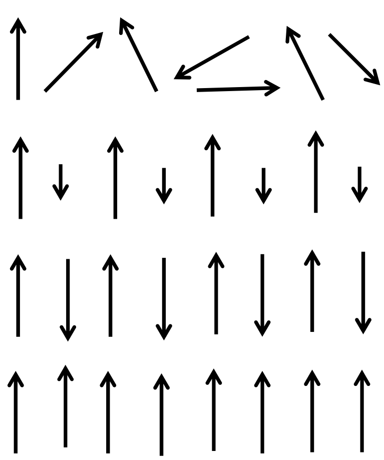
Magnetic materials have different values of magnetic permeability μ depending on their internal properties. Internal magnetic fields are produced by electrons orbiting the nuclei of the atoms. This can be modeled by a loop of current I which produces a magnetic moment $\mathbf{m}$.



If we define the area of the loop to be πa^2, the magnetic moment is represented as

$$\mathbf{m} = I\pi a^2 \hat{z}$$

(a) Miscroscopic regions where magnetic moments are alligned are called "domains". The arrows in the figures below indicate domains. Assume there is some magnetic field oriented vertically as you look at the paper. Circle the materials which have an overal magnetic moment.



(b) Which material is

(i) a paramagnet?

(ii) a ferromagnet?

(iii) an antiferromagnet?

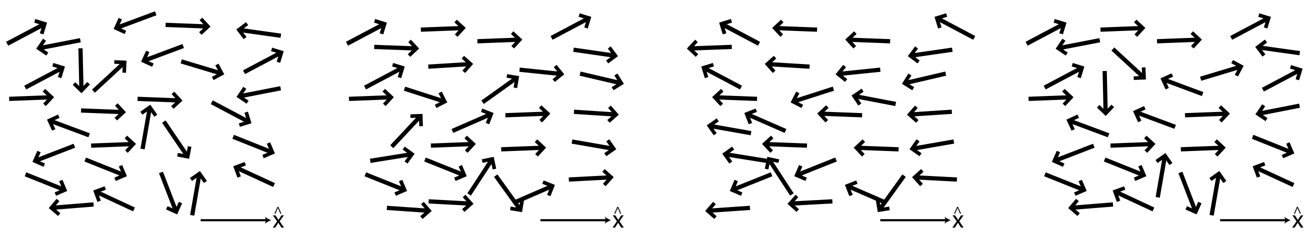
Problem 3.2 – Magnetic Materials

This problem develops your understanding of the properties of magnetic materials.

In this problem, we'll explore one of the most common uses of magnetic materials in engineering today: the data storage medium in hard disk drives.

(a) Give the consitutive relation relating **B**, **H**, and **M**. Sketch B vs. H for a material with hysteresis. Label "1" and "0" on your sketch corresponding to digital storage states.

(b) The sketches below represent the magnetization of the domains in a magnetic material corresponding to the four intercepts on the axes of your hysteresis curve. Label points (a), (b), (c), and (d) on your sketch.



(a) (b) (c) (d)

(c) As discussed in class, the points at which the hysteresis curve crosses the B and H axis are known respectively as the *Remanence* and *Coercivity*. The coercivity and remanence values are given below for two common magnetic materials:

	Permalloy	CoPtCr
Coercivity, H_c (A/m)	40	140000
Remanence, B_r (T)	0.62	0.4398

Using the information above, on the same set of axes, sketch and label hysteresis curves corresponding to the two magnetic materials. Which material would you use for the hard drive platter?

(d) For 1 mm^3 of the material you have chosen, how much energy is lost per cycle?

Problem 3.3 – Design an Inductor

Figure 3.3.1 shows a toroidal core that we have pulled out of our parts bin and want to make an inductor from. The toroid has dimensions $R_i = 13$ cm, $R_o = 15$ cm and $D = 2$ cm. The permeability of the material is $\mu = 1400\mu_0$ and the material saturates when the B field inside it reaches 1.8 T.

(a) How many turns (N) should you wrap aroung the core to make an inductor with L = 2 mH?

(b) How much current can your inductor carry before the core saturates?

(c) How much magnetic energy is your inductor storing when the current is at the point of saturating the core material?

Noting that it takes relatively little current to saturate this core, we might want to try to increase the capacity by 'gapping' the core, as is shown in Figure 3.3.2

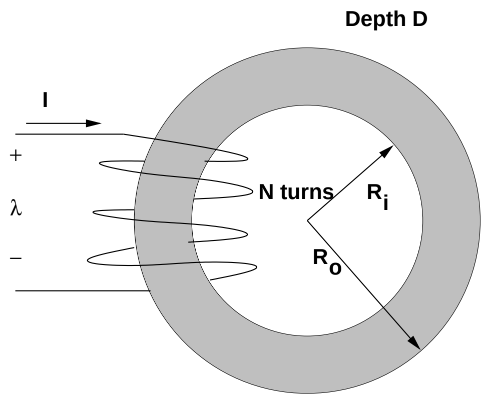


Figure 3.3.1: The basic inductor you are to design.

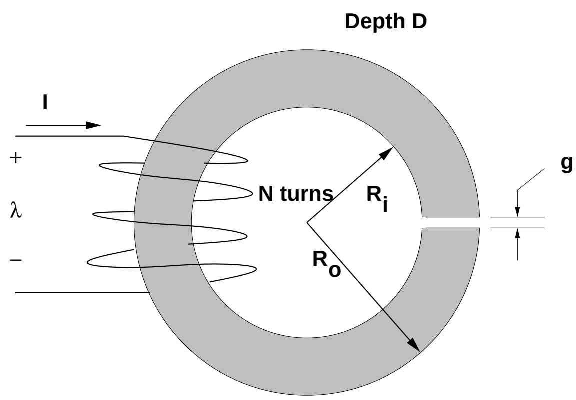


Figure 3.3.2: The second inductor you are to design.

meaning cutting an air-gap as shown in Figure 3.3.2. This gap is to have a dimension of 3 mm and will be filled with, of course, air.

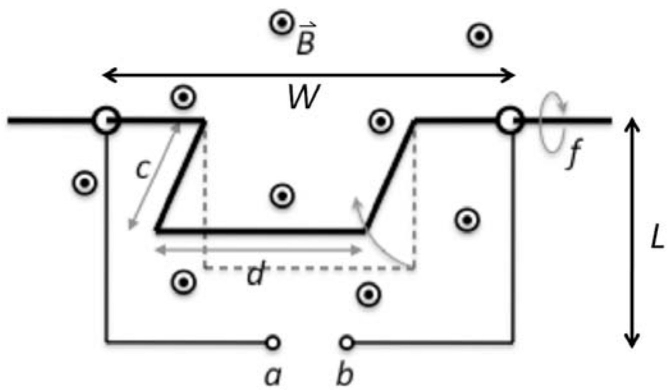
(d) Draw a magnetic circuit diagram for this situation.

(e) How many turns must you now wind on the toroid to make the inductance be L = 2 mH?

(f) How much current can this second inductor carry before the core saturates?

(g) How much energy does it store at the point of saturation?

Problem 3.4 – EMF in a Generator



A piece of wire is bent and rotated in a uniform and steady magnetic flux density, **B**, as shown in the figure above. The frequency of rotation is f rotations per second. The dashed line indicates the position the wire at time $t = 0$.

(a) Plot the induced emf between terminals a and b as a function of t. Show the polarity of the induced voltage, and indicate all of the relevant quantities on the plot. (When indicating polarity of the induced voltage, assume terminal b is connected to ground.)

(b) Start with the wire in the position corresponding to $t = 0$ (dashed line). Do not rotate the wire, but instead start decreasing the magnitude of the magnetic flux density **B**, so that $\mathbf{B}(t) = \mathbf{B_o} - kt$, where k is a constant. What is the voltage between terminals a and b? Will the wire experience a force and start to rotate?

Problem 3.5 – Short Problems on Magnetic Fields and Forces