

## Problem Set 9

(due Monday, November 11, 4:00 pm)

1. A circular loop of radius  $a$ , oriented in a horizontal plane, carries a counter-clockwise current  $I$ . A square loop of width  $b$  carries the same current  $I$ , and is located a distance  $r$  (much larger than  $a$  or  $b$ ) away from the circular loop, in the same horizontal plane. The square loop, however, is oriented perpendicular to this plane, so its area vector (related to its current by the right-hand rule) points directly away from the circular loop (see Fig. 6.6 in your text). Calculate the torque exerted on the square loop due to the circular loop. If the square loop is free to rotate, what will its equilibrium orientation be?
2. By consulting a periodic table and thinking about how electron structure in atoms works, guess which of the following materials are paramagnetic and which are diamagnetic: aluminum, copper, copper chloride ( $\text{CuCl}_2$ ), carbon, lead, nitrogen ( $\text{N}_2$ ), salt ( $\text{NaCl}$ ), sodium, sulfur, water. (Actually, copper is slightly diamagnetic; otherwise they're all what you should expect.)
3. An infinitely long circular cylinder carries a uniform magnetization  $\mathbf{M}$  parallel to its axis. Find the magnetic field (due to  $\mathbf{M}$ ) inside and outside the cylinder. (Hint: Relate this object to the infinitely long solenoid described in Example 5.9.)
4. A circular cylinder of radius  $a$  and length  $L$  carries a “frozen-in” uniform magnetization  $\mathbf{M}$  parallel to its axis. Find the bound current (magnitude and direction, in terms of the variables just listed), and sketch the magnetic field created by this cylinder, both inside and outside, assuming  $L \approx 2a$ . Make a separate sketch showing  $\mathbf{M}$ , and a third sketch showing  $\mathbf{H}$ , both inside and outside the cylinder, being sure to clearly show the directions of these vectors. Compare this “bar magnet” to the “bar electret” whose electric field and  $\mathbf{D}$  field you sketched in a previous problem set.
5. A coaxial cable consists of two very long concentric cylindrical conducting tubes, with radii  $a$  and  $b$  (with  $a < b$ ), separated by a linear insulating material of magnetic susceptibility  $\chi_m$ . A current  $I$  flows down the inner conductor and returns along the outer conductor, and these currents are distributed uniformly around each. Find the magnetic field in the region between the tubes. As a check, calculate the magnetization and the bound currents, and confirm that (together, of course, with the free currents) they generate the correct field.
6. In the previous problem set you used Mathematica to calculate and plot the vector potential and magnetic field of a circular current loop. Now write up a formal presentation of that calculation (and its result), following the same guidelines as in the writing exercise in Problem Set 6. Explain everything at a level that would be appropriate for a student who is also taking this class but who hasn't yet done this calculation (e.g., yourself, about a week ago). Include your Mathematica code in your presentation as appropriate. Be sure to *motivate* the calculation, that is, say why it is a worthwhile calculation to do, and also be sure to provide some insightful interpretation of the

result. Again I encourage you to type your presentation, but you may neatly write it by hand if you prefer. Please look over the comments on your previous writing exercise for further guidelines. If you were unable to finish the Mathematica calculation on the previous problem set, you'll have to do it now (but I'd be happy to help).

By no endeavour  
Can magnet ever  
Attract a silver churn!

—W. S. Gilbert, *Patience*