Problem Set 9
(due Friday, November 9, 4:30 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. Type up a formal presentation of this calculation using $\text{LaTeX}$, explaining it 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). Be sure to motivate the calculation, that is, say why it is a worthwhile calculation to do. If you find that you want to use the symbol $\varpi$, I suggest that instead you simply write $| \mathbf{r} - \mathbf{r}' |$. To typeset computer code you can put it between \begin{verbatim} and \end{verbatim}. You will also need to include
the resulting plot as a figure, with an appropriate caption. (Refer to it in the main
text as “Figure 1.”) I won’t describe all the steps required to export the figure from
Mathematica, upload it into Overleaf, and incorporate it into your document—but I’d
be happy to help you with this process if you wish. Alternatively, you may simply
print the figure on a separate page and hand-write the caption.

By no endeavour
Can magnet ever
Attract a silver churn!

—W. S. Gilbert, Patience