The University of British Columbia

Physics 108 Assignment # 7:

THE MAGNETIC FIELD

Wed. 23 Feb. 2005 — finish by Wed. 2 Mar.

1. FRICTION *vs.* **THE LORENTZ FORCE:** A 2-kg copper rod rests on two horizontal rails 2 m apart and carries a current of 100 A from one rail to the other. The coefficient of static friction between the rod and the rails is $\mu_s = 0.5$. What is the smallest magnetic field (not necessarily vertical) that would cause the bar to slide?

2. CYCLOTRONS: (Neglect any relativistic effects.) Suppose that we want to build a small cyclotron for protons using a magnet with a uniform field over a region 1 m in radius such that the protons reach a maximum kinetic energy of 20 MeV at the outer radius of the magnet.

(a) What magnetic field must the magnet produce?

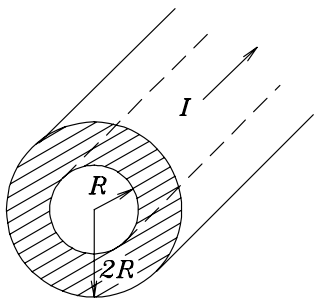
(b) At what frequency must the "dee" voltage oscillate?

Now suppose we want to build a cyclotron to accelerate electrons *without a magnet*, using the Earth's magnetic field (assume $B = 5 \times 10^{-5}$ T) to keep the electrons moving in circles.

(c) What is the radius of the electron orbit at 100 eV?

(d) What is the frequency (in Hz) of the RF electric field we must supply to the cyclotron "dees?"

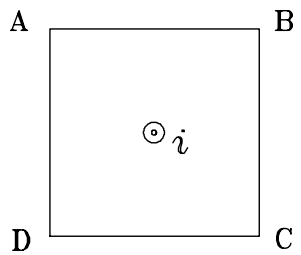
3. HOLLOW CYLINDRICAL CONDUCTOR: A thick-walled hollow conducting cylinder carries a uniformly distributed current I. The (centred) hole in the middle has a radius of R and the outer radius of the conductor is $2R$. Derive an expression for the strength of the magnetic field B as a function of radial distance r from the cylinder axis, in the range from $r = R$ to $r = 2R$; then *plot* (*i.e.* sketch, showing axis labels, scales and values at key points) $B(r)$ in the range from $r = 0$ to $r = 4R$.



Challenge Problems:

The three questions on the first page comprise Assignment 7. If you do them all correctly you will receive full credit. The three "challenge problems" on this page are harder and not required. However, *if you choose*, you can work out *all three* for *extra credit* — a maximum of an extra 20% overall. Please note that you *must try all three* of these to get the extra points.

1. MOTION OF AN ELECTRON IN A MAGNETIC FIELD: An electron has a kinetic energy of 400 eV as it moves through a region containing a uniform magnetic field $\vec{\boldsymbol{B}} = B\hat{k}$ of magnitude $B = 4 \times 10^{-4}$ T. At $t = 0$ it is at the origin of coordinates $(x = 0, y = 0, z = 0)$ and has velocity components $v_y = 0$ and $v_x = v_z > 0$. Find the position of the electron (x, y and z) 10 ns later. [1 ns = 10^{-9} s]

2. FORCE ON A CURRENT-CARRYING CONDUCTOR: A long, rigid conductor, lying along the x axis, carries a current of 6 A in the $-\hat{\imath}$ direction. A magnetic field $\vec{\boldsymbol{B}} = 3.0\hat{\imath} + 6x^2\hat{\jmath}$ (with x in m and B in mT) is present. Calculate the vector force on the 3-m segment of the conductor that lies between $x = 1.0$ m and $x = 4$ m.

3. AMPÈRE'S LAW: A wire carrying a current of 2001 A coming out of the page, as shown, emerges from the centre of the square ABCD whose side is 3 m in length. (a) Using Ampère's Law, find the average value along AB of the magnetic field component parallel to AB. (b) Find the magnitude and direction of the magnetic field at the midpoint of the line AB.