1. (5 points) Use Ampere’s Law to derive the magnetic field inside an infinitely long solenoid of radius \( b \) with \( n \) turns/length of current \( I \). Assume all quantities are given in CGS units, i.e., current in esu/sec, radius \( b \) in cm, and \( n \) turns/cm.

2. (15 points) (a) Find the force between 2 parallel wires of length \( L \), one with current \( I_1 \) and the other with current \( I_2 \). Assume both currents flow in the same direction, and that the wires are separated by distance \( a \). Assume that all quantities are given in CGS units, i.e., currents \( I_1 \) and \( I_2 \) are in esu/sec, and length \( L \) and distance \( a \) are in cm.

(b) Show that the wires either attract or repel by considering explicitly the directions of the magnetic fields and forces. Explain the direction of the magnetic field of one wire at the position of the second wire. Then find the direction of the force on the second wire. Finally, find the direction of the magnetic field of the second wire at the position of the first wire, and the direction of the force on the first wire.

3. (30 points)
(a) (5 points) Two protons are moving parallel to one another a distance \( r \) apart, with the same velocity \( \beta c \) in the lab frame. Use the equation below for the electric field of a moving charge to show that, at the instantaneous position of one of the protons, the electric field \( E \) caused by the other, as measured in the lab frame. Sketch the field lines in the lab frame.

(b) (5 points) The force on the proton measured in the lab frame is not due only to the electric field, however, as there is also a magnetic field accompanying each moving proton in the lab frame. Find the total perpendicular force in the proton rest frame and then transform it back to the lab frame. (Recall that the perpendicular force is always largest in the rest frame of the particle on which it acts.)

(c) (20 points) Now find the magnetic field of one proton at the position of the other one in the lab frame. Find the magnetic force of one proton on the other (both magnitude and direction) in the lab frame. Now show that the total force in the lab frame, including both electric and magnetic forces, agrees with your answer in part (b).

Electric field of moving charge

\[
E' = \frac{Q}{r'^2} \frac{1 - \beta^2}{(1 - \beta^2 \sin^2 \theta')^{3/2}}
\]

Lorentz transformation equations for fields, with primed quantities measured frame \( F' \) moving in \(+x\) direction with speed \( v \) as seen from \( F \):

\[
\begin{align*}
E'_x &= E_x \\
E'_y &= \gamma(E_y - \beta B_z) \\
E'_z &= \gamma(E_z + \beta B_y) \\
B'_x &= B_x \\
B'_y &= \gamma(B_y + \beta E_z) \\
B'_z &= \gamma(B_z - \beta E_y)
\end{align*}
\]
4. (20 points) A long copper rod 8 cm in diameter has an off-center cylindrical hole, as shown in the diagram, down its full length. This conductor carries a current of 900 A flowing in the direction “out of the paper.” Find the direction and strength in gauss, of the magnetic field at the point P which lies on the axis of the outer cylinder.

5. (30 pts) Consider the following circuit with known emf's (voltages) $E_1, E_2, E_3, E_4, E_5$ and known resistances $R_1, R_2, R_3, R_4, R_5, R_6, R_7$.
(a) (5 points) First find the equivalent resistance, $R_{eq}$, for the combination of $R_5, R_6, \text{and } R_7$ as shown.
(b) (25 points) Assign currents and their directions on the diagram. Using $R_{eq}$ in place of $R_5, R_6, \text{and } R_7$, write a set of simultaneous equations which could be solved for all of the currents. (You do NOT need to actually solve for the currents.) Please draw on the diagram below which loops you are using for the Kirchhoff voltage law and which nodes you are using for the Kirchhoff current law.