

8.02X Electricity and Magnetism

Problem Set 8

~~Issued: Sat, Apr 2~~

~~Due: Fri, Apr 8, 4PM < note Date + Time!~~

~~Note that the exp MF write-up from both lab partners is also due on 4/8 4PM!~~

~~Reading suggestions (from Young & Freedman)~~

~~Mon: Electromagnetic Induction I~~

~~Wed: Electromagnetic Induction II~~

~~Fri: Quiz 3 Review~~

~~Homework Problems (30 points total)~~

~~**Problem 1 (10 points)** Two parallel wires carrying currents in the same direction are found to attract each other.~~

- ~~(a) Give a step-by-step explanation of why the wires attract each other, due to the field created by moving electric charges and the forces on moving charges. Use pictures and words, but not equations~~
- ~~(b) Again using pictures and words show that you get repulsion if the currents in the two wires run anti-parallel.~~

~~**Problem 2 (10 points)** You have a horizontal cathode ray tube (CRT) in a lab room which has been adjusted such that the electron beam should produce a single spot in the center of the front screen. However, you find that the spot is offset to the right, when viewed from the front.~~

- ~~(a) You realize that the offset could be caused by an electric or magnetic field or by a misalignment of the cathode. How can you determine the cause of the problem without any instruments to detect electric or magnetic fields and without removing the CRT from the room?~~
- ~~(b) If the cause was an magnetic field, what direction would the field have, relative to the original direction of the electron beam?~~

~~**Problem 3 (10 points)** The Large Hadron Collider at CERN, Geneva, will accelerate lead nuclei to an energy of 2.8 TeV/nucleon. The nuclei will follow a circular trajectory of 27km circumference~~

- ~~(a) What is the momentum of each nucleus [note: The relativistic relationship between energy and momentum is $E = \sqrt{p^2 c^2 + m_0^2 c^4}$]?~~
- ~~(b) How big is the magnetic field of the dipole magnets that hold the nuclei on their trajectory?~~

- (c) Would it be possible to build a linear accelerator of 100m length that achieves the same final energy of the particles? What electric field would be necessary for this and how does it compare to the typical fields inside atoms?

~~Experiment MF (Magnetic Force)~~ ~~(20 points total)~~

~~Note that check off and experiment write up for experiment 'Magnetic Force (MF)' are due on Fri, 4/8. There will be 2 bonus points for MF check off on 4/4 and 1 bonus point on 4/5.~~

~~The lab hours are Mon 3-5, Tue. 7:30-9:30 pm, Wed 7:30-9:30 pm, Thu 3-5, Fri 12-3.~~

~~You will be graded according to the following criteria:~~

- ~~1. Your Experiment: Magnetic Force apparatus works (you will need to demonstrate a trial run during the check off).~~
- ~~2. Your understanding of the underlining physical principles involved in the experiment.~~
- ~~3. You may be asked a question during the check off about how to calculate the magnetic permeability constant $\mu_0 = \frac{1}{\text{slope}} \left(\frac{\rho A t g d}{n_1 n_2 r} \right)$.~~

~~Problem 1 (10 points)~~

~~In your experiment, depending upon the winding direction of the coils, the current through them will generate magnetic forces such that the coils will either attract or repel each other causing them to move.~~

- ~~a) Is your apparatus set up to repel or attract? Briefly explain how you intend to measure the current that flows through the coil that will produce a magnetic force that will just balance the weight of the foil.~~
- ~~b) What is the radius r of your coils? What is the distance d between your coils?~~
- ~~c) You will measure the current that will produce a magnetic force that will just balance one, two, and three squares of the foil. Suitable weights are 2 cm by 2 cm squares of foil. For each number of weights, n , make several measurements of the current that balances the weight. Average your values.~~

Problem 3 (10 points)

a) Each nucleus has energy $E = 208 \times 2.8 \text{ TeV} = (208 \times 2.8 \times 10^{12})(1.6 \times 10^{-19}) \text{ J} = 9.3 \times 10^{-5} \text{ J}$. Using the relativistic equation $E^2 = p^2 c^2 + m_0^2 c^4$ for the energy and momentum, we get

$$\begin{aligned} p &= \sqrt{\frac{E^2}{c^2} - m_0^2 c^2} = \\ &= \sqrt{\left(\frac{9.3 \times 10^{-5} \text{ J}}{3 \times 10^8 \text{ m/s}}\right)^2 - [208(1.67 \times 10^{-27} \text{ kg})(3 \times 10^8 \text{ m/s})]^2} \approx \\ &\approx 3.1 \times 10^{-13} \frac{\text{kg} \cdot \text{m}}{\text{s}}. \end{aligned} \quad (1)$$

All of p comes just from the first term. We could have seen this much easier in the eV units. The rest mass (and energy) of the lead nucleus is $E_0 = 208(1.67 \times 10^{-27} \text{ kg})(3 \times 10^8 \text{ m/s})^2 = 3.1 \times 10^{-8} \text{ J} = 0.2 \text{ TeV}$. The total energy when accelerated is $208 \times 2.8 \text{ TeV}$. Obviously, almost all of the energy comes from momentum. Thus $p \approx 208 \times 2.8 \text{ TeV} = (208 \times 2.8)(1.6 \times 10^{-19})/(3 \times 10^8 \text{ m/s}) = 3.1 \times 10^{-13} \text{ kg} \cdot \text{m/s}$.

b) The radius of the path of a charged particle in a magnetic field is $R = \frac{p}{qB}$, so the magnetic field needed to keep the nuclei on their trajectory is

$$B = \frac{p}{qR} = \frac{3.1 \times 10^{-13} \text{ kg} \cdot \text{m/s}}{(1.602 \times 10^{-19} \text{ C})(27 \text{ km})} \approx 71 \text{ T}. \quad (2)$$

c) A linear accelerator of length $L = 100 \text{ m}$ would have to have a potential difference of $V = E/q \approx 6 \times 10^{14}$ between its ends. This would mean an electric field of magnitude $E_{\text{field}} = V/d \approx 6 \times 10^{12} \text{ V/m}$, which is ridiculously high. For comparison, the fields inside atoms have strengths of order

$$E_{\text{atomic}} \approx \frac{kq}{r_a^2} \approx \frac{(9.0 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(1.602 \times 10^{-19} \text{ C})}{(10^{-10} \text{ m})^2} \approx 10^{10} \frac{\text{V}}{\text{m}}. \quad (3)$$