Electromagnetism (PHYS 295): Guide 7

Spring 2024 v1.6

Intro:

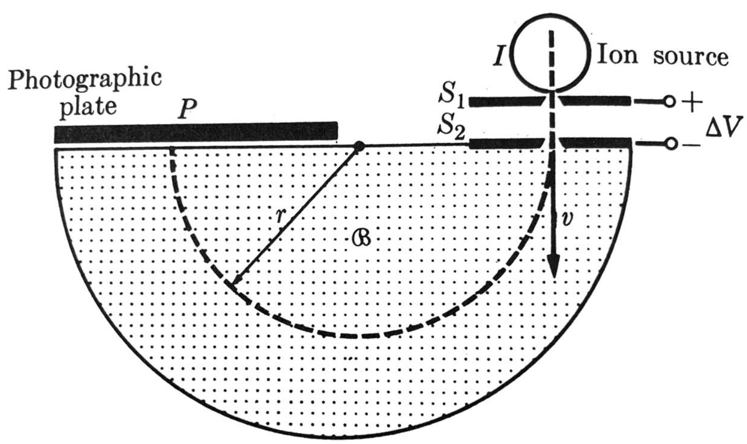
We have now finished section on special relativity. David Morin's quick recap of SR is appendix G of PM. Just before break we studied the case of a neutral, current carrying wire and found a new field (the magnetic field), a new force (the Lorentz force $\mathbf{F} = q\mathbf{v} \times \mathbf{B}$*, and a new law(Amperé's law). With all this new material we have a bunch of things to do: (1) find how these field transform, (2) see some of the physical effects, (3) learn how to use Ampré's law, (4) learn about the curl, as well as (4), finish our last little bit of SR, how energy and momentum behave.*

Reading:

- Chapter 5 section 9 is similar to the argument we discussed before break, which suggested the 'new' magnetic field
- Chapter 6 sections 1 and 2
- Chapter 2 sections 14 - 17 (on the curl of a vector field)
- (Optional - recommended) Appendix G in PM - this is David's review of special relativity

Problems: Due Friday, March 29 before class

(1) Positively charged particles are accelerated by a voltage ΔV. They enter a region with a uniform magnetic field B (curly B in the schematic) and are deflected as shown. They end up on a detector, the "photographic plate".



(Thanks to Alonso and Finn for the diagram.)

(a) What is the direction of the magnetic field?

(b) Show that the charge to mass ratio (q/m) is given by

$$\frac{q}{m} = \frac{2\Delta V}{B^2 r^2}$$

(c) Suppose $\Delta V = 5.0$ kV, $B = 1.0 \times 10^{-2}$ T. Find the distance separating the arrival location on the plate for ions (of charge e) for two isotopes of zinc, ^{68}Zn and ^{70}Zn. These isotopes have different numbers of neutrons, as indicated by the different mass numbers.

In the following problems sketch the set-up, including the current flow. Sketch the expected, magnetic field and you "Amperian loop". Carefully compute the left and right hand sides of Amperé's law. Finally find the magnetic field.

(2) Finding **B**-fields I: Use Amperé's law to find the magnetic field a distance d from a long straight wire. (As we did in class.)

(3) Finding **B**-fields II: A great way to create almost-constant **B**-fields is to wrap wire around a cylinder in a helical pattern and then run a current through the wire. This is called a solenoid. Use Amperé's law to find the magnetic field inside a long solenoid made with n turns per length. Assume that the wire carries a current I. What is the magnetic field just outside the solenoid, far from the ends?

(4) Finding **B**-fields III: Use Amperé's law to find the magnetic field just outside current-carrying sheet. Assume that the sheet carries a linear current density K.

(5) (2 pts.) **J.J. Thomson discovers the electron!**

> *"The electrified particle theory has, for purposes of research, a great advantage over the aetherial theory, since it is definite and its consequences can be predicted..."* - J. J. Thomson (1897)

J.J. Thomson found the charge to mass ratio of the particle we now call electrons.

(a) Examine the schematic of the Thomson apparatus on the next page. The distance L is from the origin of the x axis (on the left of the capacitor) to the screen on the right. Notice the accelerating potential ΔV_a on the left hand side and the cross section of the capacitor with potential ΔV_p. Sketch the electric field lines, including a couple of fringing field lines, and equipotentials of the capacitor.

(b) Show that while the particle is between the plates its y position is

$$y(x) = \frac{1}{2}\frac{qE}{m}\frac{x^2}{v_x^2}.$$

(c) Show that the position on the screen where the particle lands is given by

$$y(L) = \frac{qE}{m}\frac{b}{v_x^2}\left(L - \frac{b}{2}\right).$$

(d) Sketch the particle's trajectory.

(e) The problem with the above equation for position is that it involves *two* unknowns q/m (what Thomson wished to find) and v_x. Ugg. Thomson reduced the number of unknowns by an ingenious way of measuring v_x - the "velocity selector". He introduced a magnetic field until the spot on the screen returned to the $y = 0$ position on the screen. Find the direction of the magnetic field which restores the beam to its original undeflected position on the screen. Explain your reasoning.

(f) Draw a free body diagram and show that the velocity is given by

$$v_x = \frac{E}{B}.$$

Since the spot remains well defined in the magnetic field, what can you infer about the velocities of the particles in the beam?

(g) If you combine all the relevant expressions the ratio of charge to mass is

$$\frac{q}{m} = \frac{y(L)\,\Delta V_p}{\left(L - \frac{b}{2}\right) b\, B^2 d}$$

Suppose that b and L are 4.00 cm and 20.00 cm, respectively, and that the spacing between the deflecting plates is 1.50 cm. Under a potential difference of $\Delta V_p = 150$ V, the deflection of the spot on the screen is observed to be $y(L) = 2.6$ cm. The magnetic field which restores the spot to the center has a strength of 4.5 $\times 10^{-4}$ Tesla. Calculate the velocity of the beam particles and the charge-to-mass ratio.

The Thomson Experimental Setup