College Physics II
Lab 9: Moving Charges in Magnetic & Electric Fields

Taner Edis and Peter Rolnick

Introduction

A moving charged particle will feel electric and magnetic forces. In this experiment you will observe both. The beam of electrons (the moving charges) will be visible because they will strike a screen that glows when struck—similar to a old-style TV or oscilloscope screen. You will control the speed of the electrons by adjusting the accelerating voltage, V_a, which speeds them up. You will control the electric field E, which is perpendicular to the direction of motion of the electrons, by controlling another voltage, V_d, the deflecting voltage. The magnetic field B will be created by two coils of wire with a current I in them—you will control I.

Part 1: Experimental Data

You will have either an old or new vacuum bubble where you will produce an electron beam. The wiring for the new one is a a bit of a nuisance:

- To heat some metal to make electrons available, hook up the two green outlets on the 5kV power source to F1 and F2.
- The voltage difference you will use to accelerate the electrons is also set by the 5kV power source. Hook up the low (blue) outlet to C5, and the high (red) to A1.
- The deflecting voltage is set by the larger power source. Hook up the high outlet on the 500V power source to A1, and the low to G7.

- The high current outlet on the larger power source is to control the magnetic field. Connect both low and high to the A's on the copper loops. One of the connections should include an ammeter to measure the current. Take an extra wire and connect Z to Z directly. If you need to flip the direction of magnetic deflection, switch the wires between the high and low outlets.

The wiring on the older equipment is more intuitive; I will show you how.

Play with the controls, and observe how applying both electric and magnetic fields deflects moving charges, in different ways. **Warning:** This expensive equipment can be damaged easily. Don't turn anything on or up unless you are sure it is set up correctly.

Now try to set the electric and magnetic forces such that they are equal and opposite, canceling each other out. On your equipment, adjust all the variables you control, so that the path of the electron is a straight line, and measure and write down values for V_d, V_a, and I. Do this for at least two different sets of values—more if you have time.

To hand in for part 1

- Your observations: how does the electron beam deflect (in what direction, in a tighter or less tight curve) as you change the voltages and curents you control?
- All measured values V_d, V_a, and I for each trial.

Part 2: Charge to mass ratio

The values you took for activity 1 can lead you to determine the charge to mass ratio, e/m_e, for an electron. To do this, imagine that you ask for the help of a physics senior who is supposed to know how to calculate such things. She works for a bit, and presents you with an equation:

$$\frac{e}{m_e} = \frac{V_d^2 R^2}{2kd^2 V_a N^2 I^2} \tag{1}$$

She then explains that

- V_d: The deflecting voltage you set,
- V_a: The accelerating voltage you set,
- I: The current you put through the coils.
- R: The radius of the coils generating the magnetic field,
- d: The distance V_d is applied across,
- k: A constant depending on the geometry, which in this case she guesses is about $k = 9.0 \times 10^{-7}$ N/A^2
- N: The number of coils in your set-up; $N = 320$.

Measure R and d. Use your data and the above information to calculate an experimental value of e/m_e for an electron for two or more trials, and average those values for a final experimental result.

Then, using accepted values for the electron charge and mass,

$$e = 1.60 \times 10^{-19} \text{ C}$$

$$m_e = 9.11 \times 10^{-31} \text{ kg}$$

calculate the accepted value of e/m_e for an electron.

To hand in for part 2

Your calculated e/m_e values for each trial, your final result for experimental e/m_e, the accepted value of e/m_e, and comparison with the accepted value.

Part 3: Checking your results

If you are satisfied that your results are close enough to what you should get, you need not do this activity. You can go home if you like.

Chances are, however, that with unfamiliar equipment and so forth, you might have made a mistake. Go over your measurements and calculations to check them. *I will not correct errors with units or other minor things as I go around, but I might tell you whether you have a mistake or not.*

If you find a mistake, correct it. And again, if you're satisfied with your results, you can go home.

If there's still a serious discrepancy over e/m_e, you have to ask whether there was a problem with what you did, or with equation (1) the physics senior gave you. For example, you might suspect that the k value she assumed is incorrect.

If you need to check whether equation (1) is correct, do these:

- When a particle of charge q is moving with speed v in perpendicular $\vec{E}$ and $\vec{B}$ fields, the particle will feel no force only if the effect of the electric and magnetic fields cancel:
$$qE = qvB \quad \Rightarrow \quad E = vB \tag{2}$$
- A particle of mass m and charge q being accelerated through a voltage V_a will have a kinetic energy given by
$$\frac{1}{2}mv^2 = qV_a$$
- The magnetic field B from a group of coils depends on the current I in the coils, the number of turns N of the coils, and the radius R of the coils:
$$B = \frac{kNI}{R}$$
where k is a proportionality constant which depends on the geometry of the particular set-up. Its value should be comparable to μ_0.
- If a voltage V_d is applied across a distance d, then the electric field E in that region is
$$E = \frac{V_d}{d}$$

If you have everything set so that equation (2) holds, in other words, if your particle is moving at constant speed in a straight line and thus there is no net force on it, you can now derive an expression for $q/m = e/m_e$ as a function of V_d, V_a, d, R, k, N and I. Compare this to equation (1).

To hand in for part 3

Whatever calculations and checks that you did. If you derived the expression for e/m_e yourself to check, show me your work and final expression.