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.

Activity 1: Experimental Data

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 activity 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.

Activity 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 the ratio e/m_e for an electron to two significant digits.

To hand in for activity 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.

Activity 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

$$K = qV_a = \frac{1}{2}mv^2$$

- 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. Compare this to equation 24.3 on page 775 of your textbook, to get a rough idea of the magnitude of k.
- 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 activity 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.