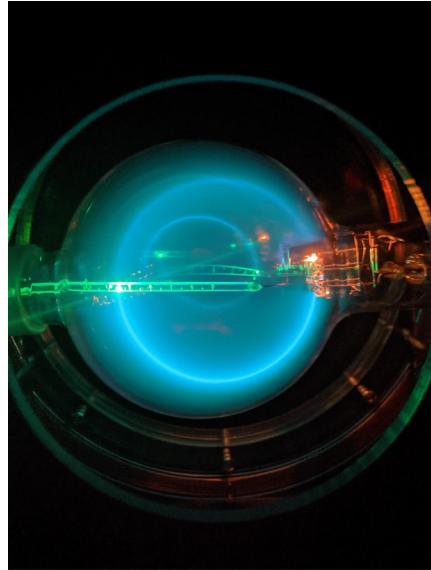


Lab 7

Particle Physics



Physical Models: Particle Charge-to-Mass ratio

Analysis Tools: Nonlinear fitting, Linear Fitting, Chi-Squared parameter

Experimental Systems: Charge-to-Mass Ratio Apparatus

Equipment: Bar magnets

Safety Concerns: Be careful while handling the apparatus, it's delicate and can break easily.

Introduction

In the Prelab for this week you learned how, in theory at least, our charge-to-mass ratio apparatus can generate a fast moving beam of charged particles using electric fields, and direct their paths using magnetic fields. By synthesizing several relations from Physics II, we were able to arrive at the formula:

$$\frac{125R^2\Delta V}{32\mu_0^2N^2I^2} = \left| \frac{q}{m} \right| r^2 \quad (7.1)$$

This is all rather complicated, and depends on many assumptions. However, the upshot is that if this works, the left hand side is treated as y and the quantity r^2 is treated as x , this has the form:

$$y = \left| \frac{q}{m} \right| x \quad (7.2)$$

So we can extract the charge-to-mass ratio q/m (and uncertainty) of the elementary particle by doing a linear fit!

Let's recall the definitions of the variables involved:

- R is radius of the coils used to produce the magnetic field. You can measure it with a meterstick.
- ΔV is the voltage used to accelerate the charged particles. It's reported to you on the apparatus, and you can change it.
- μ_0 is a constant which, like G for gravity, determines the strength of magnetic forces. It's given by $\mu_0 = 4\pi \times 10^{-7} \text{ N/A}^2$
- N is the number of turns in the coil in the apparatus. For our setup this is $N = 130$
- I is the current, which is proportional to how many particles are flowing in the beam and how fast they're moving

Like the formula itself, the uncertainty δy is also intricate. But it can be simplified down to:

$$\delta y = y \sqrt{\left(2 \frac{\delta R}{R}\right)^2 + \left(\frac{\delta \Delta V}{\Delta V}\right)^2 + \left(-2 \frac{\delta I}{I}\right)^2} \quad (7.3)$$

You're welcome to try to derive this yourself, but you're free to just take it as given.

We will have two goals in this lab. First, we'll want to test if this model is even accurate at all, or at least for what range of variables it's reliable for vs. not. Second, to the extent that it works, we'll use it to determine the charge-to-mass ratio of the particles in the beam.

This is all quite similar to how particle physicists working at particle accelerators study elementary particles. Like them, we'll be interested in trying to determine which particles we're observing. We can do this using the charge-to-mass ratio!

Here are some possibilities:

- The particle beam could be made up of electrons, which have $q/m \approx -1.76 \times 10^{11} \text{ C/kg}$
- The particle beam could be made up of muons, which have $q/m \approx -8.50 \times 10^8 \text{ C/kg}$
- The particle beam could be made up of tau leptons, which have $q/m \approx -5.06 \times 10^7 \text{ C/kg}$
- The particle beam could be made up of protons, which have $q/m \approx +9.57 \times 10^7 \text{ C/kg}$
- It could be none of the above. You're welcome to search online and propose your own identification if you conclude none of the listed particles are a match.

It could also be the antiparticle of any of these, which has the same charge-to-mass ratio but opposite sign. Or, it could be none of these!

Part 1

In this part of the lab, you'll need to:

- Check if the linear model is accurate.
- Determine the *magnitude* $|q/m|$ using the linear fitting techniques, find its uncertainty using the uncertainty in the slope formula, and calculate a t-score of this against the closest manual value.
- Determine if the charge is positive or negative. You can do this using the magnet. Recall that magnetic field lines produced by a magnet point *away* from the North pole and *towards* the South pole. Recall that positive and negative charges are bent in opposite directions by the same magnetic field. Alternatively you could use the compass to find the direction of the field created by the coils.

You may wish to use the compass to help you determine the sign of the charge. But if you do you should make sure your compass is calibrated correctly to point north. Does it?

Quick Check: Turn on the machine. Wait a bit as it heats up. Once the voltage indicator appears, raise it from 0 volts to 120 volts or more. Set the current to about 1 amp. You should see a glowing beam curling around, as in the picture on the first page. Here are our elementary particles!

Pick up the bar magnet. You can point the magnet towards the beam. The beam should distort. This is evidence the particles are charged as expected.

Designing Your Experiment: Now design a high precision experiment to systematically investigate whether the model even works at all, or which points it works for vs. doesn't.

Refer to the “Lab 5 Analysis Tools” if you need a reminder on how to evaluate a model using the χ method.

Tip: Make sure that when you fit your data the slope is accurately representing the precision of your measurements. For instance, if your slope is reading “8E+10” and your precision is to 3 digits, you change the Category to “number” or “scientific” to read “7.98E+10” instead.

Conducting Your Experiment: Go for it. Above all, try to minimize uncertainty as much as you can so that you can be confident in your conclusions.

Forming a Conclusion: Does the linear model work? Can you identify the particle?

Check in with Another Group: Check in with another group. How do your results compare? Note two similarities and/or differences between what you found, and use this to inform your proposals for future iterations.

Post results to the board: Before you leave, submit your results for $|q/m|$ and its uncertainty to your TA. Do they all agree, given their uncertainties?

Writing Up Your Lab Notes for Submission

Write up your notes for Part 1 in an organized way according to the rubric provided.