e/m ratio of the electron

Concepts covered in this lab

- The electron.
- Force on an electric charge in an electric field.
- Force on an electric charge in a magnetic field.

Supporting materials

http://www.hscphysics.edu.au/resource/template.swf

Introduction

The purpose of this lab is to measure the charge-to-mass (e/m) ratio of the electron by measuring the radius of curvature of a mono-energetic beam of electrons placed in a uniform magnetic field. Consider an electron moving with velocity v perpendicular to a magnetic field of magnitude B . The radius of the electrons orbit will be

$$r = \frac{mv}{eB} \tag{4}$$

If the electron's velocity is created by accelerating it through a potential V then its kinetic energy can be written as

$$KE = eV \tag{5}$$

In this setup, Eqn. 4 can be rewritten as

$$r^2 = \frac{2V}{B^2}\frac{m}{e} \tag{6}$$

From Eqn. 6 it can be seen that if a graph of r^2 as a function of V is fit to a straight line then the slope will be $\frac{1}{B^2}\frac{m}{e}$, from which the electron charge to mass ratio can be extracted, for a fixed B.

Procedure

In addition to these instructions there is a second PDF file with details of the apparatus, some relevant equations and diagrams of how the tube is to be setup. The operation of the tube is as follows. The e/m apparatus creates a beam of electrons by heating a metal filament with a current until electrons have enough thermal energy to leave the metal. These electrons are then accelerated by a voltage between the cathode and anode of the tube, which determines their kinetic energy. The electron beam is made visible by the fluorescence of hydrogen gas within the tube. The radius of the electron's orbit can be measured using a caliper on the outside of the electron tube.

For the experiment you will initially set up a constant magnetic field using a 2 A current through the Helmholtz coils. You can then plot Eqn. 6 by measuring the radius of the electrons orbit for different values of the accelerating voltage. Fit the data to a straight line and extract the slope together with the uncertainty in the slope. Next, keeping the voltage fixed, vary the magnetic field and repeat the analysis.

Note that the supplemental notes from Leybold will tell you how to calculate B using the current through the Helmoltz coil, the radius of the coils, and the number of turns of the wire.

Notes of caution

The following is pulled directly from the "*Safety notes*" provided by the Leybold company.

Attention: The fine beam tube requires dangerous contact voltages up to 300 V for accelerating the electrons. Other voltages that are connected with this dangerous contact voltage also present a contact hazard. Dangerous contact voltages are thus present at the connection panel of the holder and at the Helmholtz coils when the fine beam tube is in operation.

- Connect the connection panel only via safety connecting leads.
- Always be sure to switch off all power supplies before connecting and altering the experiment setup.
- Do not switch on the power supplies until you have finished assembling the circuit.
- Do not touch the experiment setup, particularly the Helmholtz coils, during operation.

Danger of implosions: The fine beam tube is a evacuated glass vessel with thin walls.

- Do not subject the fine beam tube to mechanical stresses.
- Operate the fine beam tube only in the holder (555 581).
- Connect the 6-pole plug of the holder carefully to the glass base.
- Read the instruction sheet supplied with the fine beam tube.

  Helmholtz coils may be charged with more than 2 A for short time only.

Prelab Questions

1. Use the Biot-Savart Law to calculate the field at the center of two Helmholtz coils. For a Helmholtz coil the vertical seperation between the two coils is equal to the radius of the coils[6].
2. Derive Equation 4.
3. Derive Equation 6.
4. Discuss why the Helmholtz coil is made of two coils symmetrically placed above and below the electron tube. Why should this be better than a single coil around the tube?

[6] Note that if you were to just look up "Helmholtz coil" on Wikipedia then that might give you the answer, but you won't learn as much.

Lab report guidelines

Introduction

1. Discuss the method by which e/m will be measured.
2. Introduce the basic equations

Procedure

1. Draw a circuit diagram of your setup.
2. Outline the general steps you used to take the data.
3. Discuss any special tricks you used to get accurate measurements of the radius.

Data and Analysis

1. Graph the data according to Eqn.6 and fit it to a straight line.
2. Make sure you have a reasonable estimate for the uncertainties on the data points.
3. Make sure to obtain both the slope and the uncertainty in the slope for both measurements.
4. Make sure to properly label the graph axes and data points.

Conclusions

1. Compare your value of e/m with the tabulated values.
2. The intercept of your lines should, in principle, be zero. If they are not, discuss what type of systematic errors would lead to a non-zero intercept.
3. Suggest the possible sources of error in the experiment.
4. Discuss whether varying the B field or the Voltage is more accurate.

Supplementary materials

Some other materials from Leybold on the Helmholtz coil and the operation of the experimental apparatus (P6131_E.pdf).