Ratio of Charge to Mass for the Electron

Equipment:

Helmholtz coils with electron tube unit.
One Agilent Lab volt unit (0-12 V, 3A D.C. for filament)
One HV Lab volt units (0-500V), also used for e-gun heater.
One Voltmeter for acceleration voltage
6 banana plug cables.

Purpose:

To measure the ratio of two fundamental constants (the ratio of the charge of an electron to its mass).

Method:

A stream of electrons is accelerated through a measured potential difference. This stream is projected onto a uniform magnetic field, perpendicular to the velocity vector of the electrons, that causes the electrons to bend into a circular path, much as the ions in a mass spectrometer. The value of the ratio of charge to mass (e/m) is computed from the relationships between the measured accelerating potential difference, the magnetic flux density, and the diameter of the circular path which the electron beam describes.

Theory:

From the definition of the magnetic induction **B** in a magnetic field, the force **F** acting upon a charge e that is moving with velocity **v** perpendicular to the direction of the field, is given by

$$F = eBv$$

Since the direction of this force is always perpendicular to the velocity vector it follows that the force is a centripetal one. Such a force causes the electron to move in a circular path. the centrifugal force of reaction of the electron is equal in magnitude to the force exerted on the electron by the magnetic field. Hence

$$F = \frac{mv^2}{r} = eBv$$

where r is the radius of the circular path of the electron. (note: This r is not the same as R in the expression for magnetic flux below.)

The kinetic energy aquired by an electron that is driven by a potential difference V is given by:

$$eV = \tfrac{1}{2}mv^2$$

The apparatus used in this experiment makes it possible to vary/measure the values of V,B, and r. Manipulation of the equations above makes it possible to express the ratio e/m through the values, which can be experimentally observed.

Magnetic field B

The magnetic field which bends the beam is produced by a current in two Helmholtz coils. These coils are mounted vertically and, therefore, produce a field in the horizontal direction. When the distance between the coils is equal to the radius of either coil, a nearly uniform field is produced at the midway point. this is because the field contributed by each coil is diminishing with a constant rate over a short distance. The decrease of the field of one coil is compensated for by the equal increase in the field produced by the other coil.

The electron tube is held in a socket mounted between the coils, and on their common axis. The currents in the coils must be in such directions that the fields of the coils are in the same direction along their common axis. The magnitude of the flux density B at the central point is given by

$$B = \frac{8\mu_0 NI}{\sqrt{125}R}$$

where N is the number of turns per coil, I the current in the coils, R the coil radius, and μ_0 is the permeability of free space ($4\pi \times 10^{-7}$ Tm/A). The flux density is given in Tesla (T=Wb/m^2) when I is in amperes and R is in meters. B should be in the order of a few mT. For your equipment, you should have 130 turns per coil.

$$B = 7.8x10^{-4} \times I \quad \text{T/A}$$

Apparatus:

The major items consist of an electron tube, and a pair of Helmholtz coils. Within the electron tube an electron "gun" is mounted, with its center line coincident with the vertical axis of the tube. The gun consists of an indirectly heated cathode which supplies the electrons; a grid, charged to a positive potential with respect to the cathode, which serves to focus the electron beam; and a circular plate, which is held at a high positive potential and thus accelerated the electrons. The electron stream is projected horizontally through a small hole at the center of a small disk on the upper end of the gun. A scale can be viewed through the tube. If the lighting is lowered, it is easy to see the complete circular path of the electron beam when a magnetic field is applied as well as the reflection of the beam on the reflective scale. (Note: You are observing the light radiated from helium atoms that undergo collisions with the electrons!).

The Helmholtz coils are wound on non-magnetic rings. The number of turns of the coils is marked on the equipment.. The strength of the magnetic field can be adjusted by changing the current in the coils. Variation of either the accelerating potential difference in the tube or the strength of the magnetic field will cause the radius of the circle described by the electron beam to vary.

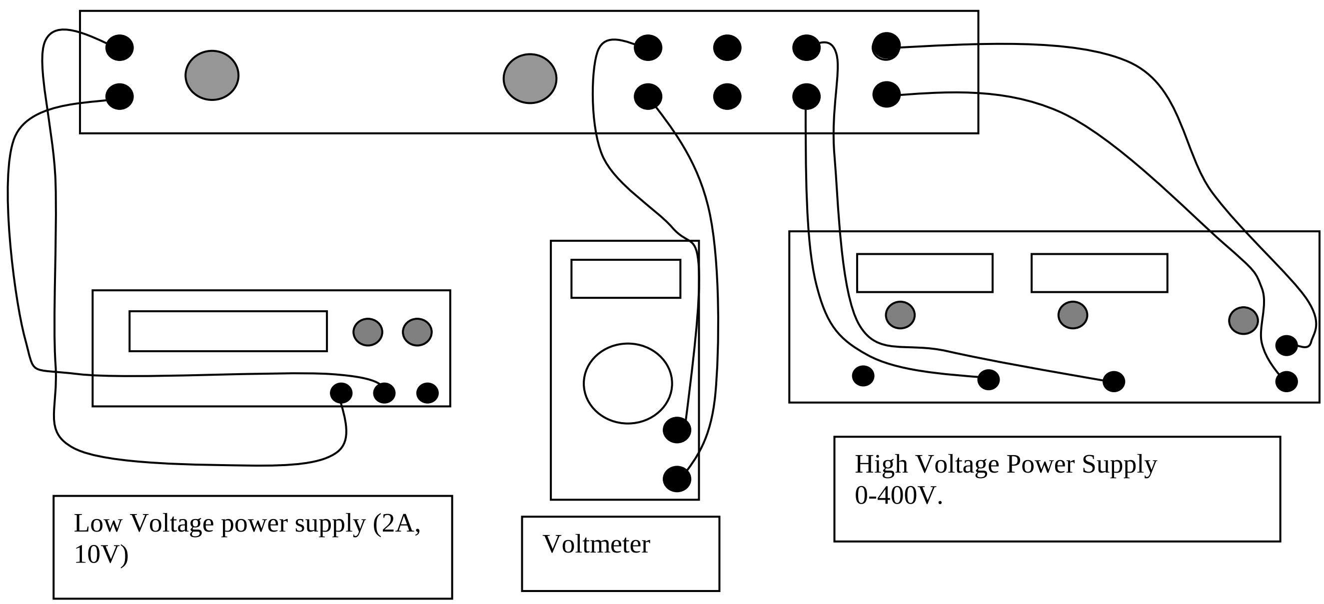
Setup:

1. Connect the apparatus to the power supplies as shown in the circuit below. Make sure you connect the right polarity to the tube (positive for grid and plate, negative for filament). Use a common ground for all power supplies, i.e connect the grounds of the power supplies. Note: current is measured in series!! Otherwise you will blow a fuse. Connect the ammeter for the B-field current correctly first (input in 10A-common, reading on 10A) before you turn on the amperage

2. Adjust the AC knob on the High Voltage Power Supply to 6. After allowing the cathode to heat for about 2 min apply the plate potential and notice the blue stream of electrons which rises from the hole in the center of the disk.

3. Set the current button on the Helmholtz coils and electron tube unit all way to 10 and flip the switch to e/m.

4. Apply a current, 3-5 amps to the field coils, by adjusting the current on the Low Voltage Power Supply, until the beam bends into a complete semicircle (the circle should be larger to then the ruler). Adjust the focus knobs on the apparatus to make a stronger beam.



Procedure

1. Measure the circle radius, the current through the coils, and the acceleration voltage, record in table 1 (line the original beam with the reflection on the beam to make accurate measurements). For 6 different accelerations Voltages, try to repoduce the radius r, by changing the current through the coils and thus the B-field.
2. With a high current through the coils, vary the acceleration Voltage, record data in table 2.

Analysis / Questions:

- Derive the equation for e/m from the given equations by eliminating the velocity v.
- From the recorded data and the use of the equations calculate the values of e/m obtained from the sets of observations. Calculate the accepted value of e/m.
- Make a table with all your data sets, with your measured e/m, and with a column of the percentage difference to the standard value of e/m.
- Are there any sources of systematic errors? (your e/m chnages systematically with radius or voltage). Identify possible sources of error.
- What is the value of e/m for a proton?

Table 1: Constant Radius

#	V (Volts)	I (Amp)	r (m)	e/m	%error
1					
2					
3					
4					
5					
6					

Table 2: Constant Current

#	V (Volts)	I (Amp)	r (m)	e/m	%error
1					
2					
3					
4					
5					
6					