IM.2. Charge to Mass Ratio of the Electron

1. Purpose:
To determine the charge to mass ratio of the electron.

2. Apparatus:
Helium filled tube,
Helmholtz coil,
power supplies,
multimeters.

3. Theory:

The charge to mass ratio of an electron is measured using a set of Helmholtz coils and an electron beam tube.

When an electron (or any charged particle) moves through a magnetic field it experiences a force ("Lorentz force") given by

$$F = e\ \mathbf{u} \times \mathbf{B} \qquad (1)$$

where e = charge on an electron
$\mathbf{u}$ = velocity of the electron
$\mathbf{B}$ = magnetic flux density

If **B** is perpendicular to **u** then the electron will move in a circle whose plane is also perpendicular to **B,** and the magnetic force (Lorentz force) provides the centripetal force for this circular motion, i.e.

$$mu^2/r = euB \qquad (2)$$

where m = mass of electron
r = radius of circular path.

In this experiment the velocity of the electron is due to its being accelerated across a potential difference, V. The electron will then have kinetic energy

$$mu^2/2 = eV \qquad (3)$$

Solve Eq. (3) for u and substitute into Eq. (2) to obtain

$$e/m = 2V / (Br)^2 \qquad (4)$$

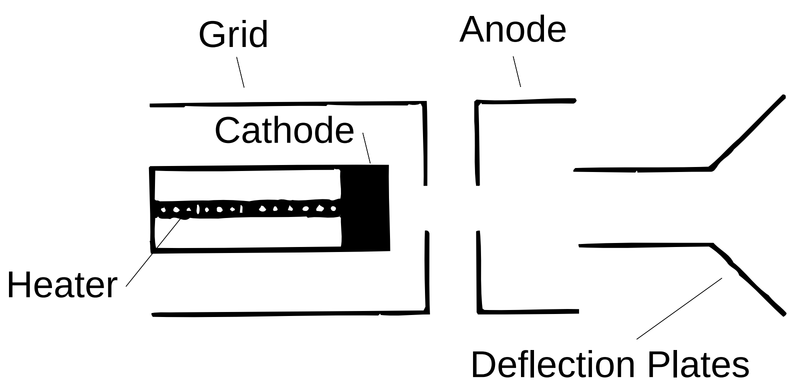
4. Apparatus:

The magnetic field is supplied by the *Helmholtz coils*. They are constructed so that the distance between the two loops is approximately equal to their radii (both 15cm in our case). This arrangement gives maximum uniformity of the field over a large volume near the center. Each of the coils contains 130 turns. The magnetic flux density at the center is given by (derive this in your report):

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

where N = number of turns in each coil,
I = current through the coils in amperes,
a = radius of coils in meters, and
μ_o = permeability of free space

The major piece of equipment is the electron beam tube. It is filled with helium at a pressure of10^{-2} mm Hg, and contains electron gun and deflection plates.

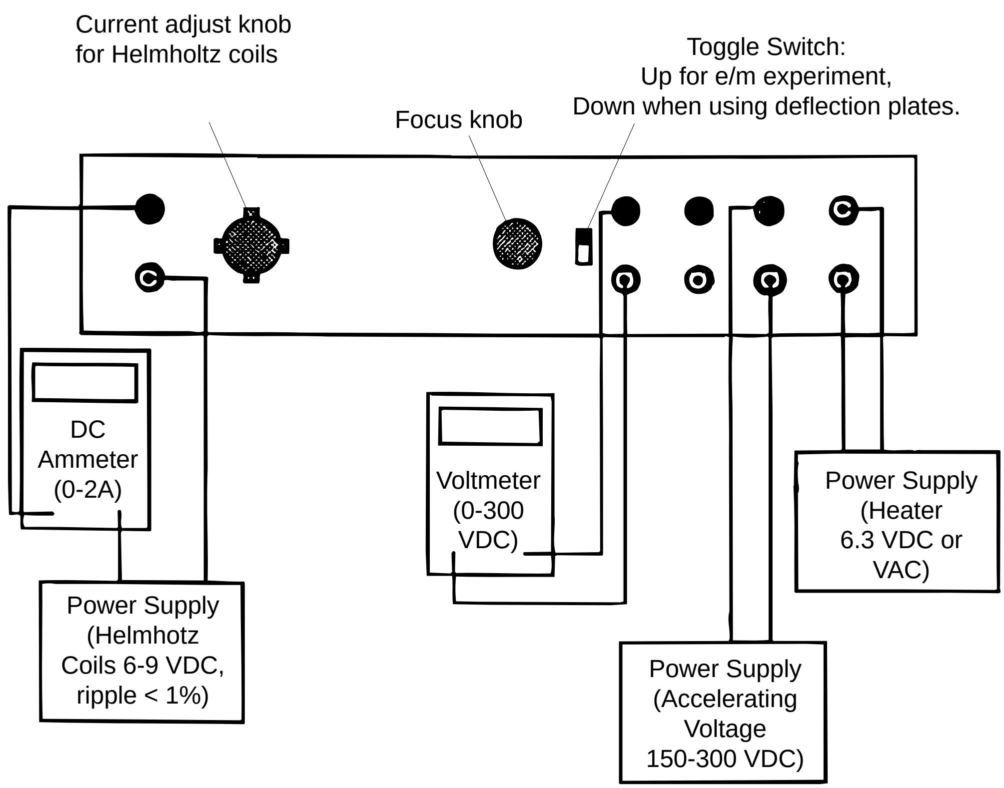


The electron gun has a cathode consisting of a nickel cylinder which is closed on the electron - emitting end. The cylinder is heated by a helical coil of fine tungsten wire, which is mounted inside the cylinder. This tungsten filament heats the cathode to a bright red, so that electrons will be thermionically emitted. The heater voltage should be 6.3 volts DC or AC (r.m.s.). Great care should be exercised to ascertain that this voltage is never exceeded, as a burned out filaments render the tube useless (~$600).

The electrons emitted by the cathode are accelerated across to the anode by a potential difference, which should not exceed 300 V. Some of the electrons pass through a hole in the anode and thus form the electron beam.

A terminal box is used to connect the power supplies to the Helmholtz coils and to the tube electrodes. In addition to providing you some protection from electrical shock, the box also contains some protective resistors which protect the anode, control cylinder, and deflection plates from excessive currents. Please note that some voltage will be dropped across the protective resistor in the anode circuit, so that the anode voltage applied to the terminal box will not be the actual accelerating voltage. *You will need to know the actual accelerating voltage*. It is therefore suggested that the current in the anode circuit be measured, so that a correction can be made for the IR drop across the 2kΩ resistor.

The wiring of the terminal box is simple and appears below.



4. Procedure:

Switch on the heater voltage. When the cathode begins to glow red turn up the anode voltage just until a thin beam of light can be seen passing straight through the tube. *(CAUTION: All exposed anode connections should be taped for your protection.* Anode voltage should not exceed 300 V.) When a magnetic field is applied, the electrons will begin to curve around in a helix. Rotate the tube so that the electrons are launched perpendicular to the field, and the path will become a circle. Explain in your report what the influence of the Earth's magnetic field is on your measurement, and how you could correct for it, if necessary.

The diameter of the circle can be measured by using the mirrored scale which is attached to the back of the rear Helmholtz coil. By lining up the electron beam with its mirror image in the mirrored scale, you can measure the radius of the beam path without parallax error. Since the beam has a finite width, the measurement should be repeated a sufficient number of times to reduce the random error in the measurement and to allow a standard deviation to be calculated. Note that if the radius used is quite small, then the percentage error will be quite large. Measurements should be made for at least two different radii, and you should try different combinations of accelerating voltage and magnetic field, for a total of at least ten different measurements.

Please ascertain that your power supplies for the accelerating potential (voltage regulated) and Helmholtz coils (current regulated) are stable and not fluctuating. You will probably find that the precision of the electrical measurements is sufficiently good that they will not need to be included in your error propagation calculations. (But note that there will still be an error in the magnetic field due to errors in the measurement of the dimensions of the coils, and this will need to be propagated).

5. Analysis:

Every set of magnet current, accelerating voltage and orbit radius provides an independent measurement of e/m. You should also estimate the uncertainties on your measurements of the directly measured quantities V, I, r, and a, and from these determine an uncertainty for every individual measurement of e/m. Take the average of all of these e/m values and determine the standard deviation.
If the uncertainties of the individual e/m measurements are very different, then it is recommended to use a weighted average rather than the straight mean (see statistics hand-out).
Compare the average of the individual uncertainties with the standard deviation. You should also plot V vs $(Br)^2$ and determine e/m from the slope of the straight line. If you find a non-zero intercept, try to interpret what this means.