# PHY 252 Lab 2: $e/m$ for electrons

## Fall 2008

In this experiment you will measure $e/m$, the ratio of charge to mass of the electron. This is the experiment that J.J. Thomson did at the Cavendish Laboratory in Cambridge in 1897, for which he received the Nobel Prize in 1906.

The setup (Fig. 1) consists of a visible beam cathode ray tube used to produce a beam of electrons of known energy. The tube contains an electron gun which emits, accelerates and focuses electrons. The electrons with charge $q = e$ are accelerated over a voltage $V$, so that they acquire a kinetic energy of $E_k = e \cdot V = (1/2)mv^2$ in the classical limit. The tub also contains a trace amount of gas which fluoresces when struck by electrons, so that you can see the beam trajectory by eye.

The tube is supported at the center of a pair of large Helmholtz coils producing a uniform magnetic field $B$ perpendicular to the velocity of the electrons. Therefore the electrons will be deflected to trace a circular path with a radius determined by $e/m$, the accelerating voltage $V$ and the magnetic field $B$ (see Eq. 1). Helmholtz coils produce a very uniform magnetic field in the region half-way between the coils defined by

$$B = \frac{\mu_0 N I R^2}{(R^2 + x^2)^{3/2}}, \tag{1}$$

where $\mu_0 = 4\pi \times 10^{-7}$ Henry·m$^{-1}$ is the magnetic permeability of free space, $N =$ is the number of turns on each coil (72 in your apparatus unless you have been told otherwise), $I$ the coil current, $R$ the radius of the coils, and $2x$ the distance between coils.

The apparatus involves one circuit to drive the magnetic field in the Helmholtz coils, and another circuit to both drive the current in the filament and the accelerating voltage for the electrons (Fig. 2).

## 1  Measurement

Determine $R$ and $x$ (and their errors!) with a meter stick. Then, for a given coil current $I$, vary the accelerating voltage $V$ and read off the radius $r$ of the electron orbit. This is done most accurately by tuning the voltage $V$ such that the edge of the beam coincides with one of the 5 cross bars in the tube. The precise location of the spacebars is given in the Figure. Perform measurements for as many voltage settings as possible, then repeat the sequence for several different current settings. Be careful **not to exceed** the maximum allowed current!
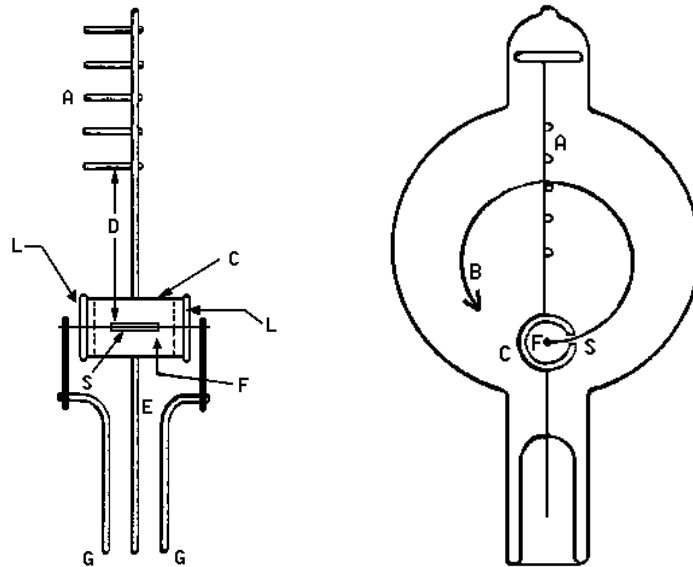
Figure 1: Detailed section of the filament assembly, and right angle view. Items in the sketch: **A:** Five cross bars attached to staff wire. **B:** Typical electron trajectory. **C:** Cylindrical anode. **D:** Distances from filament to far side of cross bars: (1) 6.5 cm, (2) 7.8 cm, (3) 9.0 cm, (4) 10.3 cm, (5) 11.5 cm. **E:** Lead and support wire for anode. **F:** Filament (cathode). **G:** Lead and support wires for filament. **L:** Insulating plugs. **S:** Slit in cylindrical anode.
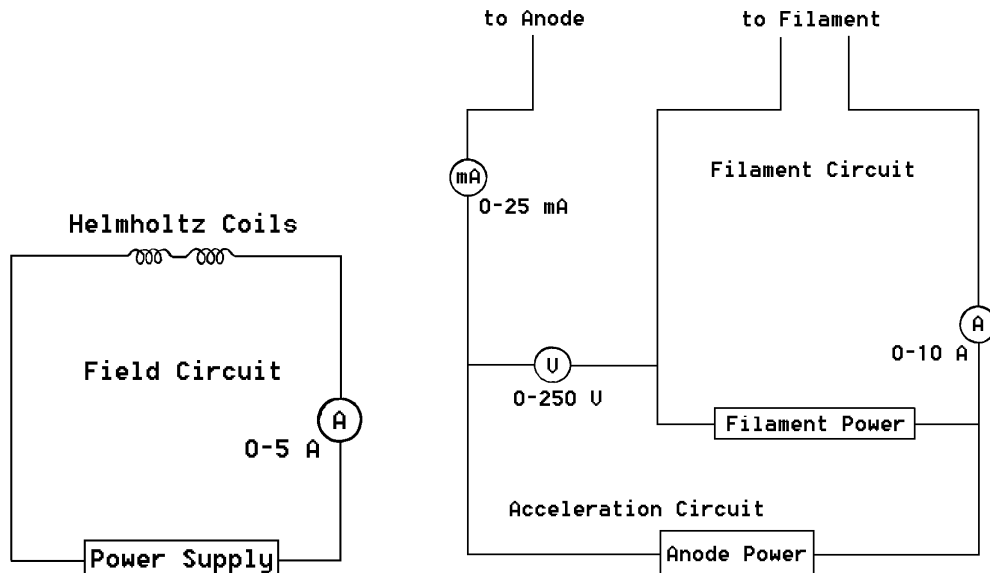


Figure 2: Circuits used. Left: for generating a magnetic field in the Helmholtz coils. Right: for heating the filament to generate the electron beam, and to accelerate it.

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# 2 Analysis

The ratio $e/m$ is given by

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

$(2)$

For each value of coil current $I$, plot $V$ versus $B^2 r^2$. You should obtain straight lines. Determine $e/m$ from the slope and average over the different values obtained for different values of $I$. Perform an error analysis estimating your uncertainties in all measured quantities. Compare your final result with the literature value and discuss possible deviations. Derive Equations 1 and 2. Discuss how you would improve the precision of the $e/m$ measurement.