

# PHY 252 Lab 3: $e/m$ for electrons

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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 tube 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 of

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

where  $\mu_0 = 4\pi \times 10^{-7}$  Henry $\cdot$ m $^{-1}$  is the magnetic permeability of free space,  $N$  is the number of turns on each coil,  $I$  the coil current,  $R$  the radius of the coils, and  $2x$  is the distance between coils. In your apparatus you are told that  $B = 7.80 \times 10^{-4} \cdot I$  in units of Webers per square meter (W/m $^2$ ), but it turns out that 1 Weber/m $^2$ =1 Tesla.

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, using the parallax-free measurement system of the bars in the mirror as described in Fig. 1. Pick 4 or 5 values of Helmholtz coil current  $I$ . At each coil current  $I$ , pick 4 or 5 values of accelerating voltage  $V$  and measure

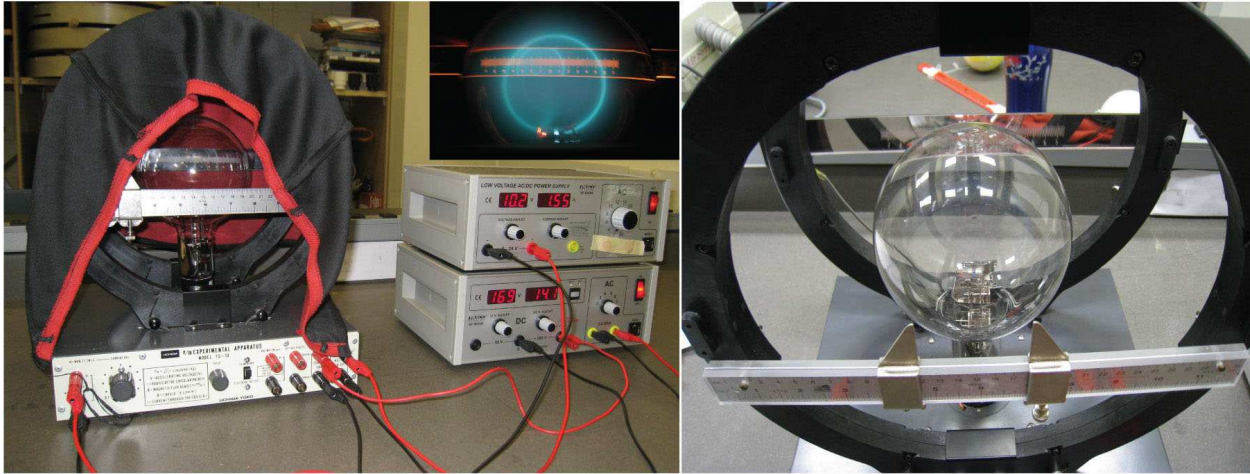


Figure 1: Apparatus used to measure  $e/m$  for the electron. The overall setup is shown at left, with an inset showing how it looks with the curving electron beam generating fluorescence in residual gas. The readout scale is shown at right. By lining your eye up so that you see the actual marker in front coinciding with its reflected image, you can eliminate parallax. Therefore by moving the measurement bars you can measure the diameter of the curved electron beam with good accuracy.

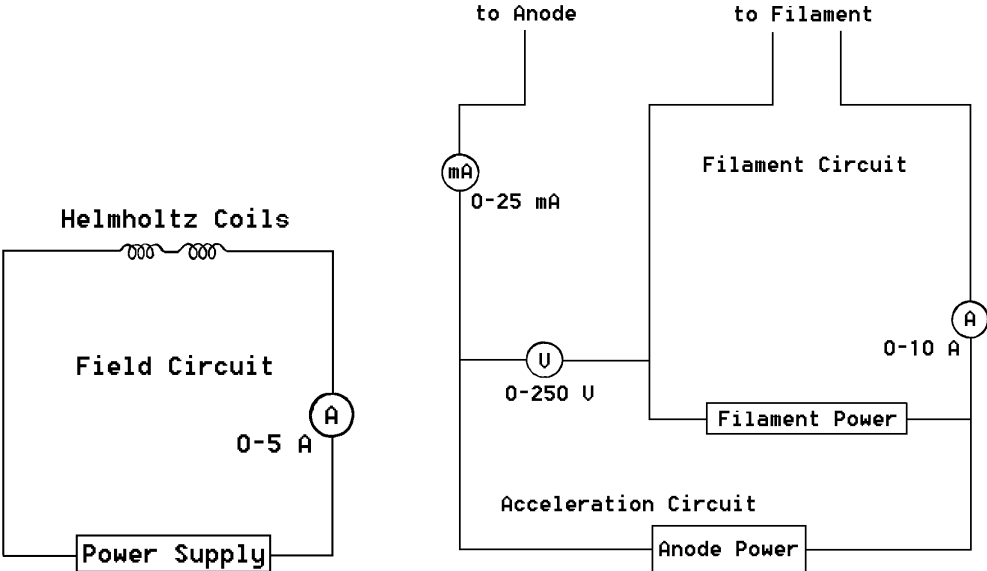


Figure 2: Circuits used. Left: for generating a magnetic field in the Helmholtz coils. Right: for heating the filament to generate the electron beam, and to accelerate it.

radius of curvature  $r$  for each voltage  $V$ . You thus have between  $4^2$  and  $5^2$  measurements. Be careful **not to exceed** the maximum allowed Helmholtz coil current!

## 2 Analysis

Use Eq. 1 and the known field relationship of  $B = 7.80 \times 10^{-4} \cdot I$  Tesla to determine the number of wire turns  $N$  in the Helmholtz coil.

The ratio  $e/m$  is given by

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

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 then average  $e/m$  over all 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. Look up the value of the earth's magnetic field and compare it to the typical fields  $B$  you used in your experiment. Discuss how you could improve the precision of the  $e/m$  measurement.