Ratio of Charge to Mass for the Electron

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Historical Perspective and Physics Theory

The discovery of the electron is generally credited to Sir J. J. Thompson. The methods used by Thompson led to an approach similar to that used in this procedure to measure the charge to mass ratio (e / m) for the electron in 1897. The currently accepted value for this ratio is 1.75890×10^{11} C / kg. Later Millikan, from the data acquired in his oil drop experiment, was able to calculate the mass of the electron from this ratio.

When a charged particle *e* moves with a velocity ***v*** into a region of space containing a steady magnetic field ***B*** it experiences a magnetic force given by $\vec{F}_m = e(\vec{v} \times \vec{B}) = e\vec{v}\vec{B}\sin q$. Note that this force is centripetal in nature and causes the particle to move in a circular path. If the particle enters the magnetic field perpendicular to the field lines with a constant speed:

$$F_m = m\frac{v^2}{r} = evB \qquad (1)$$

where *r* is the radius of the circular path. It should be noted that since $\boldsymbol{F}_{\mathrm{m}}$ is at all times perpendicular to the path of the charged particle, it does no work on the particle and therefore does not affect the kinetic energy of the particle.

If, however, an electric potential exists in the same region of space the charged particle experiences a change in potential energy akin to that experienced by a massive object such as a rock falling through a gravitational potential. Suppose the particle in question is an electron. The kinetic energy acquired by an electron falling through a potential difference *V* is given by:

$$eV = \frac{1}{2}mv^2 \qquad (2)$$

Combining (1) and (2) yields:

$$\frac{e}{m} = \frac{2V}{B^2 r^2} \qquad (3)$$

In this experiment you will measure *V*, ***B***, and ***r*** in order to determine e / m.

The apparatus used in this experiment is based on a design originally proposed by K. T. Bainbridge and consists of a pair of identical Helmholtz coils positioned symmetrically around an electron vacuum tube. The coils are mounted vertically and produce a field in the horizontal direction. When the distance between the coils is equal to the radius of the coils and nearly uniform field is produced at a point midway between the coils. This occurs because the field contributed by each coil diminishes at a constant rate over a short distance. The diminution of the field of one coil is compensated for by an identical increase in the field contributed by the other coil.

The electron tube is positioned between the coils and along their common axis. The magnitude of the magnetic field due to the coils at the position of the tube is given by:

$$B = \frac{8 m_0 N I}{\sqrt{125} R} \quad (4)$$

where N is the number of turns per coil, I the current in the coils, R the coil radius and m_0 the permeability of free space $\left(4p \times 10^{-7} \frac{T \cdot m}{A}\right)$. By combining equations (3) and (4) it is possible to obtain an expression that includes only constants for a given set of coils and the measurable quantities V, I, and r (the radius of the electron beam curvature).