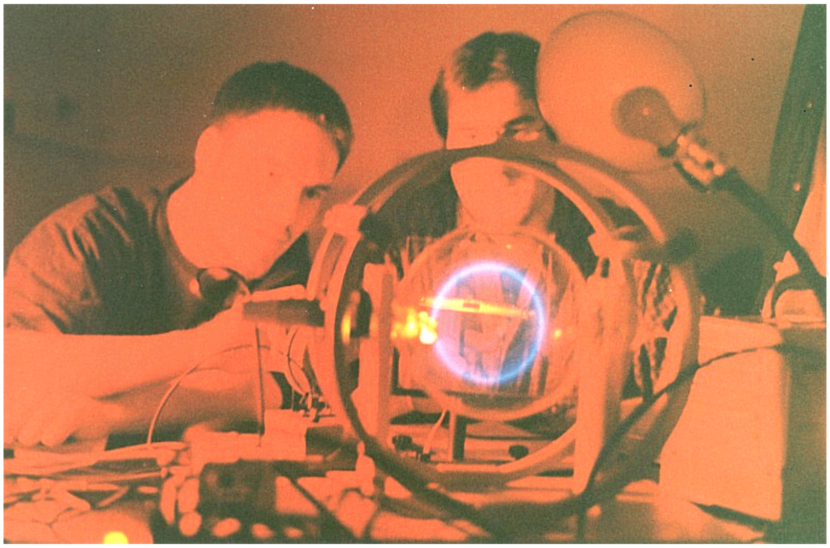
e/m FOR AN ELECTRON

REFERENCES:

R.M. Whittle and J. Yarwood *Experimental Physics for Students* Page 274.

INTRODUCTION



Picture taken by Peter Bevan

This is a variation of the original experiment carried out by J.J. Thomson in 1895. The deflection of a charge moving in a magnetic field is clearly demonstrated.

A particle of mass *m* and charge *e* moving in a magnetic induction field $\vec{B}$ will experience a force $\vec{F}$ given by:

$$\vec{F} = e\vec{v} \times \vec{B} \qquad (1)$$

where $\vec{v}$ is the velocity of the particle. The vector cross product means the $\vec{F}$ is perpendicular to both $\vec{v}$ and $\vec{B}$. If $\vec{B}$ is constant and $\vec{v}$ is perpendicular to $\vec{B}$, the particle will move in a closed circular orbit. The force on the particle is equal to its mass multiplied by its acceleration:

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

where *r* is the radius of the orbit.

Now in this experiment, the particle is accelerated through a potential difference *V* in order to reach the speed *v*. Thus in the non-relativistic approximation,

$$eV = \frac{1}{2}mv^2 \qquad (3)$$

Combining Eqs. (2) and (3), gives a curvature of the electron orbit of:

$$\frac{1}{r} = \sqrt{\frac{e}{2m}}\,\frac{B}{\sqrt{V}} \tag{4}$$

THE EXPERIMENT

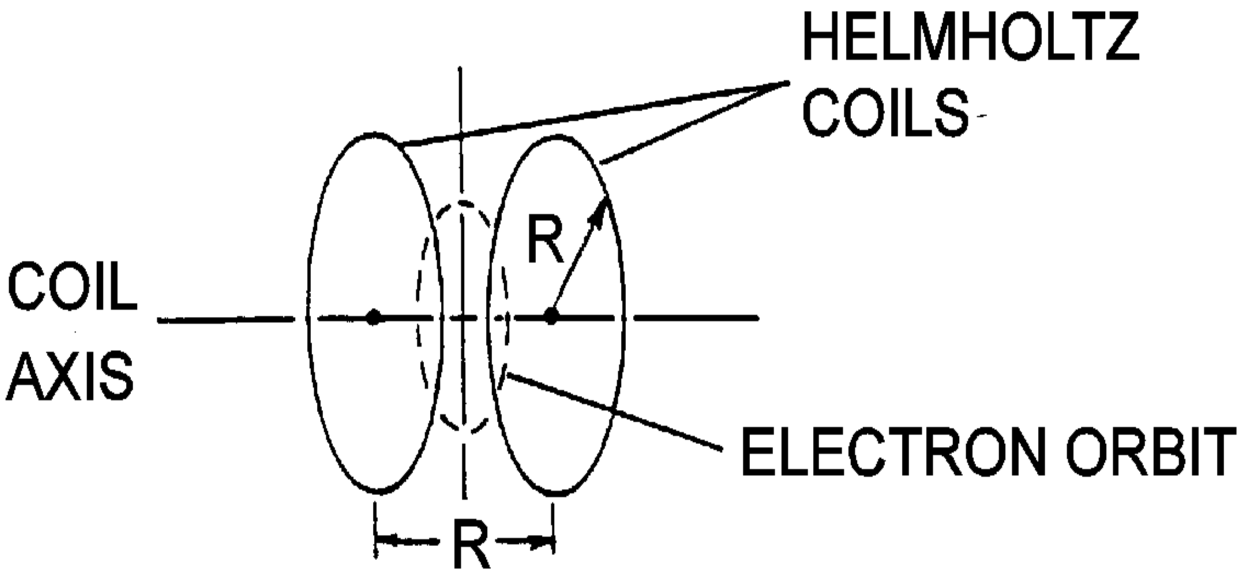


Figure 1. - Geometry of Helmholtz configuration

In this experiment, the magnetic induction $\vec{B}$ is that generated by current flowing through a pair of Helmoholtz coils. The geometry of the helmholtz configuration is sketched above in Fig. 1. Note that each coil radius is equal to the separation between the coils, this configuration giving minimum variation of *B* near the centre of the pair of coils.

Over a volume containing the geometrical centre of the configuration, the magnetic field due to the coils is directed along the coil axis and is more-or-less uniform with the value

$$B_c = \left[\frac{4}{5}\right]^{3/2} \frac{\mu_o n I}{R} \tag{5}$$

where $\mu_o = 4\pi \times 10^{-7}$ Wb A^{-1} m^{-1}. The units of B_c are Tesla; *R* is the radius of the coils (in meters), *n* is the number of turns in each coil and *I* is the current (in Amps).

The total axial magnetic induction field in the region of the electron beam is the field from the coils, B_c plus the external field from the earth and building, B_e. Thus,

$$B = B_c + B_e$$

$$\frac{1}{r} = \sqrt{\frac{e}{2m}}\ \frac{1}{\sqrt{V}} \left[\left(\frac{4}{5}\right)^{3/2} \frac{\mu_o n I}{R} + B_e \right] \tag{6}$$

or rephrased

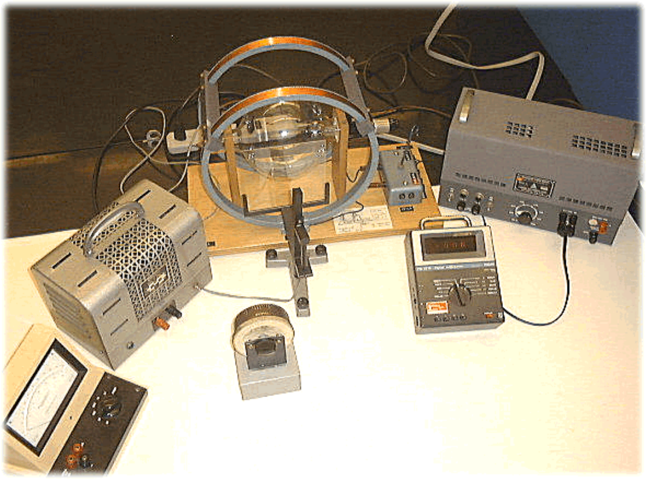
$$\frac{1}{r} = \sqrt{\frac{e}{m}}\ k\ \frac{(I - I_o)}{\sqrt{V}} \quad or \quad \frac{\sqrt{V}}{r} = \sqrt{\frac{e}{m}}\ k(I - I_o) \tag{7)\&(8}$$

where

$$k = \frac{1}{\sqrt{2}} \left(\frac{4}{5}\right)^{3/2} \frac{\mu_o n}{R} \tag{9}$$

characteristic of the coil dimensions, and I_o = a constant, proportional to the external magnetic field.

THE APPARATUS



The apparatus consists of a glass bulb containing an electron gun and hydrogen gas at low pressure. Electrons emitted by a hot filament with the gun are shaped into a beam by accelerating them through a specially shaped anode.

The anode voltage, V, is supplied by a 0 to 200 volt power supply. The coil current is provided by an 8 V D.C. power supply in series with a 10 Ω rheostat and ammeter (1 % accuracy).

The beam of electrons becomes visible when the electrons have enough kinetic energy to excite the gas by collision. The collisions, however, are sufficiently rare that the beam is scarcely affected; a full, circular trajectory should be clearly visible. The bulb can be rotated to ensure the beam follows closed paths. Their diameters can be measured with the self-illuminated scale and plastic reflector provided.

The illuminated scale, if well positioned, eliminates problems of parallax in the measurement. You should work out how to use the scale before you start your readings.

NOTE: The filament of the electron gun should be turned on 30s or more before the anode voltage and should never be turned off until the anode voltage is off. Otherwise, the tube may be damaged.

DO NOT **plug filament voltage to 100-300 V supply.**

STRATEGIES

Electron beams of various curvatures may be obtained by varying the accelerating potential V, and the coil current I. If the curvature is in a "backwards" direction so that the beam hits the glass envelope of the tube, you may rotate the tube 180 degrees in its mount. Obtain a variety of data and plot graphs of this data (do the plotting while you are taking the data) in such a way that equations (7) or (8) are confirmed or refuted. From these graphs you may obtain a value of e/m. Note that the graphs can be extended to provide more precise values of e/m if both positive and negative values of current I, and radius of curvature r, are obtained. In performing your measurements, identify your principal sources of error and both evaluate them well and minimize them.
Observe that there is an anomalous behaviour of the electron gun when the accelerating voltage V is low and the magnetic field, $B = 2kI$, is high.

Is this explainable from what you know of the electron gun construction? Does this introduce error into your measurements? In considering corrections to the value you obtain for e/m, you may wish to take account of the fact that although the field generated by the coils is very nearly constant along the axis, it decreases away from the axis. It can be shown that for off-axis distances ρ which are less than $0.2R$, the field $B_z(\rho)$ is smaller than the axial field $B_z(0)$ by less than 0.075%. For $0.2R < \rho < 0.5R$ the ratio $B_z(\rho)/B_z(0)$ is given approximately by

$$\frac{B_z(\rho)}{B_z(0)} = 1 - \frac{\rho^4}{R^4\left(0.6583 + 0.29\frac{\rho^2}{R^2}\right)^2}$$

Notice that ferromagnetic materials and other sources of magnetic field located near the apparatus may contribute to distortions of the field in the region of the electron beam, affecting the value you obtain for e/m. Evaluate whether such unwanted fields appreciably affect your measurements.

(jv - 1985, cmce - 1986)