SSM-0032 : Particles and Fields of Modern Physics

Practical Session 2, 17th November 2005

Name of Student : ....

Ask a demonstrator if you are unsure how to use the apparatus.

Hand in answers to Dr.Waters at the end of the session.

Charge to Mass Ratio of the Electron

Principle :

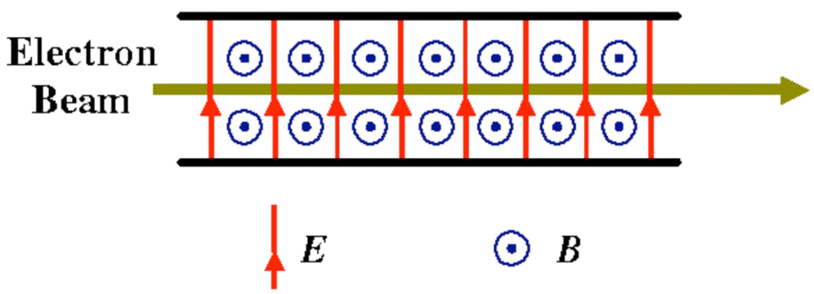
The force acting on a particle with charge q moving with velocity $\vec{v}$ through a region of electric field strength $\vec{E}$ and magnetic field strength $\vec{B}$ is given by the following vector equation:

$$\vec{F} = q(\vec{E} + \vec{v} \wedge \vec{B})$$

In the case that $\vec{v}$, $\vec{E}$ and $\vec{B}$ are mutually orthogonal, as indicated in the figure below, this equation reduces to the simple scalar equation :

$$F = q(E + vB)$$

where the resulting force is perpendicular to the direction of motion of the charged particle.



For zero deflection of the electron beam, the net force must be zero. This is only the case if the speed of the electron is given by :

$$v = -E/B \qquad [1]$$

The kinetic energy of the electrons is determined by the voltage through which they are accelerated:

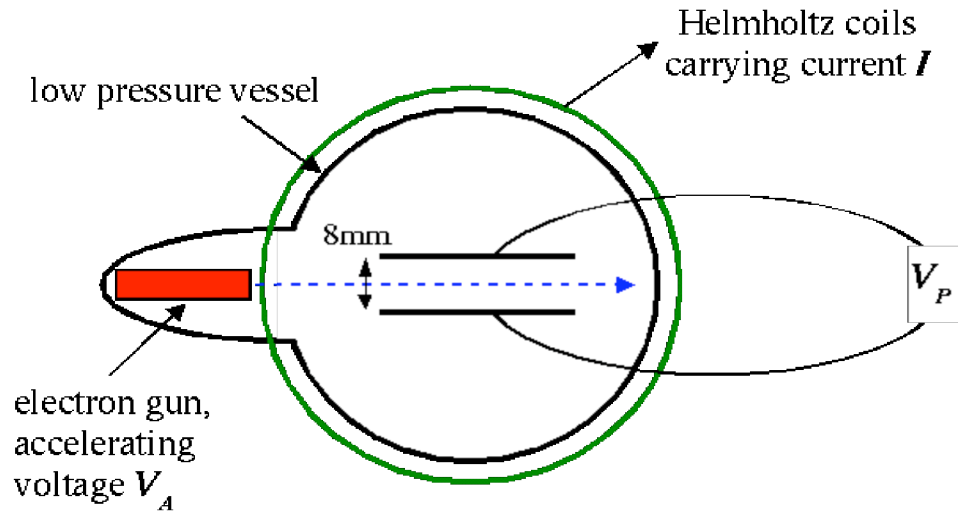
$$K.E. = qV_A = \frac{1}{2}mv^2 \qquad [2]$$

Substituting [1] in [2] and rearranging gives :

$$\frac{(E/B)^2}{2} = V_A \times \frac{q}{m} \qquad [3]$$

Hence, measurements of E, B and the accelerating voltage V_A enable a determination of the charge to mass ratio of the electron.

Apparatus :



The strength of the deflecting electric field E is given by :

$$E = V_P / d$$

where V_P is the voltage across the plates and d, the separation of the plates, is fixed at 8mm. The strength of the magnetic field B is proportional to the current I flowing through the Helmholtz coils. Providing that the coils are placed exactly 69mm apart, parallel to each other and to the beam travelling midway between the coils, the magnetic field strength in Tesla is given by :

$$B = kI$$

where $k = 4.17 \times 10^{-3}$ T/A. In addition to the plate voltage V_P and the current I, the accelerating voltage V_A can be varied.

Procedure :

Set the plate voltage V_P and the coil current I to zero, by turning off the V_P supply and the "Thurlby" coil supply respectively. Note the position of the electron beam against the white square background.

Q1 Vary the accelerating voltage V_A, measuring it using a digital volt meter (DVM). (Note: a DVM attached to the monitor output of the high voltage power supply reads $V_A/1000$) Does the trajectory of the electron beam depend on the accelerating voltage ?

Set the accelerating voltage to approximately 3000V. Turn on the V_P supply and use a DVM to measure the voltage on the deflecting plates. (Note: a DVM attached to the monitor output of the deflecting plate power supply reads $V_P/100$)

Q2 With no current flowing through the Helmholtz coils, sketch the trajectory of the electron beam when the deflecting voltage V_P is set to 50V and 250V.

With the deflecting voltage fixed at 50V, vary the current in the Helmholtz coils.

Q3 Estimate the current at which the electron beam returns to its undeflected trajectory (the trajectory corresponding to $V_P = I = 0$ as in Q1). What happens if the current is increased further ?

If the deflecting electric and magnetic field strengths are derived as described above, equation [3] can be rewritten as :

$$\frac{q}{m} = \frac{E^2}{2B^2V_A} = \frac{V_P^2}{2d^2k^2I^2V_A} = 4.49 \times 10^8 \frac{V_P^2}{I^2V_A}$$

Q4 Make a graph of the current I that must be passed through the Helmholtz coils for various plate voltages V_P , in order that the electron beam remain undeflected. A suitable step size for V_P is 50V. *Each student should make his/her own set of measurements, from different starting voltages (10V, 20V, ... etc.) but with the same step size.* From the graph, measure the charge to mass ratio of the electron.