Charge to mass ratio (e/m)

1 Aim

To determine the "charge to mass" ratio (e/m) of an electron by the helical method (long solenoid method).

2 Introduction

If an electron initially moving along or directly opposite to a magnetic field B is deflected by means of an electric field, then it follows a helical path under the influence of the magnetic field. At any instant of time during this motion, the centrifugal force is balanced by the force due to the magnetic field:

$$mw^2 r = Bev, \tag{1}$$

where v is the instantaneous velocity, w is the angular velocity and r is the radius of the helical path. This helical path can be thought of as lying on the surface of a cylinder. The axis of the solenoid also lies along a line on this surface.

Now for different values of the deflecting electric field, the radii of the paths are different (all corresponding to different cylinders attached to each other along the line). Therefore if a screen is placed at a distance, say d, from the point the electrons are deflected, the electrons following different paths strike at different points on the screen. Now note that from Eq. (1)

$$\frac{e}{m} = \frac{2\pi}{BT} \tag{2}$$

where T is the time period of one complete helical rotation of the electron. The important point here is that the above expression is independent of r. As we are talking about one complete rotation, all the electrons converge at the same point on the screen (for a particular magnetic field) no matter how much they are initially deflected.

The magnetic field inside at the center of the solenoid can be calculated from the relation

$$B = \mu_0 \frac{NI}{L} \cos\theta \tag{3}$$

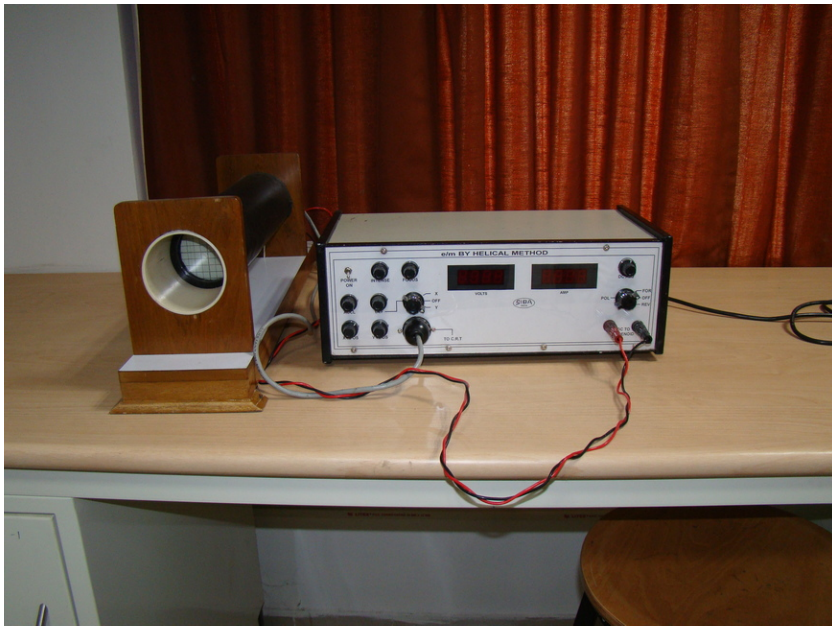

Figure 1: Apparatus for the charge to mass ratio experiment.

where N is the number of turns per unit length on the solenoid, I is the current through the solenoid and L is its length. θ can be calculated from the values of d and the deflection from the center of the screen on the application of the magnetic field. Knowing B and calculating T using $T = d/v$ where v is the initial axial velocity of an electron along PQ, obtained from $\frac{1}{2}mv^2 = eV$, V being the accelerating voltage, the ratio e/m can be easily calculated. For a long solenoid the values of θ can be assumed to be zero.

3 Apparatus in the lab and procedure

The arrangement consists of a long solenoid and a cathode ray tube placed coaxially inside the former. Electrons emitted from the electron-gun move along the axis of the system due to an accelerating voltage applied to a grid. There are two mutually perpendicular pairs of plates (X- and Y-) whose axes are perpendicular to the axis of the arrangement. Alternating voltage applied between any two parallel plates, deflects the electrons which under the action of the magnetic field follow helical paths and strike the fluorescent screen generally producing a line on the screen. The accelerating voltage, alternating deflecting voltage, intensity of the electron beam, the current through the solenoid, etc. can all be changed by means of a control panel.

1. Place the solenoid in wooden bracket such that its axis lies in the east-west direction. Mount the CRT inside the solenoid at the center. The power unit should be

kept as far away as possible to aviod stray magnetic field.

2. Connect the CRT with its power-supply by plugging the PM-8 plug into the octal base provided upon the panel.

3. Connect the solenoid with the DC power terminals Red with Red and Black with Black.

4. Turn DC volts control, DEF volts control to the minimum (fully counter clockwise) position.

5. Plug the supply to the mains. Switch on the power and wait for about three minutes for the CRT to warm up.

6. Adjust the accelerating voltage to get a spot on the screen. Adjust the Focus and the Intensity control to make a fine and clear spot. Note the accelerating voltage V_1.

7. Switch the DEF switch towards V. Apply AC voltage to the Y plates by means of the DEF volt-control. A deflectiion of 2 cm is adequate for the experiments.

8. Put DC switch towards the forward direction. Turn on the solenoid current and increase the DC voltage till the line reduces to a point.

9. Reverse the direction of DC polarity by switching towards the REVERSE direction. Adjust the DC voltage to get a fine point. Note the current IR.

10. Take simultaneous values of I by keeping the DEF switch towards X plates.

11. Increase or decrease the acclerating voltage to another value. It will be necessary to refocus the spot on the screen at each setting of the ACCL voltage. Repeat the experiment.

12. Note average current I for Y plates deflected by mean value of forward and reverse currents. In the same manner find the average current I for the deflection by X plates.

13. Plot a graph between V and I^2. Calculate the slope and use the relation $e/m = K_i.(V/I^2)$ to calculate e/m (see the Problem below). Draw separate graphs for X- and Y- measurements.