e/m Experiment (Magnetron Method)

Object:

To determine e/m (Specific Charge) for an electron by magnetron method.

Apparatus Used:

e/m apparatus consisting of power supply fitted with voltmeter and ammeter to read anode voltage (in volts), anode current (micro amp), solenoid power supply fitted with ammeter to read solenoid current(amp), magnetron valve with base and connecting wires, solenoid fitted with suitable wooden base.

Description:

A magnetron is a thermionic valve with cylindrical coaxial anode and cathode. Electrons emitted by the cathode travel radially to the anode (see Figure 1), however in the presence of an axial magnetic field (which can be obtained by placing it inside a solenoid) the path of electrons become curved. At a critical value of the magnetic field, the path of electrons just touch the anode, any further increase in magnetic field strength will result in the path of electrons so curved that they do not reach the anode hence the anode current falls to zero. Measurement of this critical field can be used to determine e/m.

Formula Used :

e/m (Specific Charge) for an electron is given by

$$\frac{e}{m} = \frac{8V}{R_a^2 B_c^2}$$

Where

V= Anode potential
R_a= Anode radius
B_c= magnetic field corresponding to critical solenoid current I_c

Theory:

Magnetron arrangement consists of a cathode in form of a wire fitted at the axis of a cylindrical anode of radius R_a .Anode is maintained at a (+)ve potential 'V' w.r.t cathode so that an electric field exists radially. A magnetic field parallel to the axis of cathode (filament) is superposed upon the electric field by placing the magnetron inside a solenoid such that its axis is coincident with solenoid axis. The strength of the magnetic field may be varied by controlling the solenoid current I_c .

Let us assume the electrons emit from the cathode with zero initial velocity and begin to accelerate towards the anode due to (+) ve potential. The velocity acquired by electron (mass 'm', charge 'e') is given by relation

$$\frac{1}{2}mv^2 = eV \quad \text{..(1)}$$

$$v = \sqrt{\left(\frac{2eV}{m}\right)} \quad \text{...(2)}$$

Magnetic Field (B) does not change the speed of an electron however modifies the trajectory of an electron depending on the magnitude of B. Following conditions may arise:

(a) $B=0$ electrons will move radially outwards and strike anode
(b) $B<B_c$ path of electrons will be curved although will strike anode
(c) $B=B_c$ path of electrons will be tangential to anode (circular)
(d) $B>B_c$ path of electrons will be highly curved and they will not reach anode

Magnetic field 'B' can be varied by varying solenoid current I_s. If the anode current (I_a) is studied as a function of solenoid current (I_s) it will be unaffected for value of 'I_s' if $I_s<I_c$ whereas for values of 'I_s', $I_s>I_c$ anode current (I_a) should practically reduce to zero. Thus 'I_c' can be determined graphically by noting the point of intersection of tangents (1) & (2) .

Tangent (1): drawn at region when anode current is constant
Tangent (2): drawn when anode current practically reduces to zero.

B_c can then be calculated as

$$B_c = \mu_0 N I_c Cos\theta \quad \text{………………………………..……(3)}$$

Where

$$\mu_0 = 4\pi \times \frac{10^{-7} weber}{amp}.m$$

I_c =Critical value of solenoid current for cut-off (in amp)

N= number of turns per meter of the solenoid

$$Cos\theta = \frac{L/2}{\sqrt{(L/2)^2 + {R_s}^2}}$$

L=length of the Solenoid (0.3m)

R_s=Radius of the Solenoid (0.065/2)m

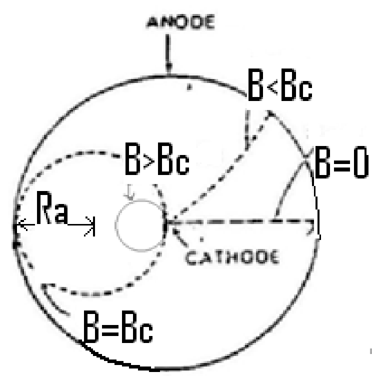

Figure 1 (draw it)

In a magnetron arrangement an electron basically moves under simultaneous mutually perpendicular electrical and magnetic fields in a circular path and for the moment of grazing anode the radius of the circular path is exactly equal to half the anode radius. Required centripetal force is provided by force due to magnetic field

$$\frac{mv^2}{r} = B_c ev \quad \text{……………………………………….……(4)}$$

$$v = \frac{B_c er}{m}$$

As

$$r = R_a/2 \quad , \qquad\qquad v = \frac{B_c e R_a}{2m} \text{.................} (5)$$

Substituting value of $'v'$ from eq. (1) and solving we get

$$\frac{e}{m} = \frac{8V}{B_c^2 R_a^2} \quad \text{C/Kg} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{./...}(6)$$

Or

$$V = \left(\frac{R_a^2}{8}\right)\left(\frac{e}{m}\right).B_c^2$$

Therefore a graph plotted V vs B_c^2 will be a straight line and by determining its slope we can calculate the e/m as follow

$$\frac{e}{m} = \frac{slope}{R_a^2/8} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(7)$$

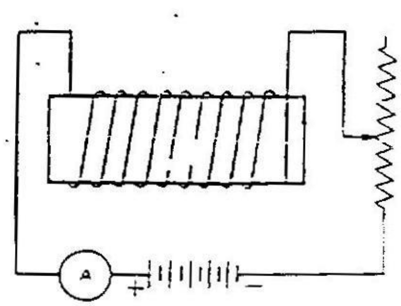

Fig.2 (Solenoid connections)

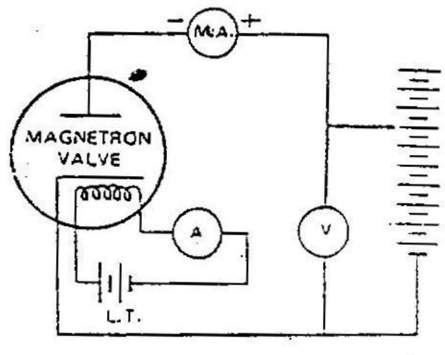

Fig.3 (Diode connections)

<u>Procedure</u>

1. Connect the diode valve and solenoid with the e/m apparatus through the cable and patch chords. (refer Fig.2 and Fig.3).

2. Put the valve well within the solenoid symmetrically along with the cable.

3. Switch on the e/m apparatus and set the solenoid current to zero (i.e. B=0). Apply a constant anode potential V (say 2 volt) wait for 2 minutes and note the corresponding anode current in the micro-ammeter provided on the front panel keeping the solenoid current at zero.

4. Apply some current I_s (say 0.2 amp.) in the solenoid with the constant current source built- in the e/m apparatus and note the corresponding anode current (I_a μA.) <u>at fixed anode potential</u> V (say 2 volt). Increase the solenoid current gradually say to 0.4, 0.6………. Amp and so on and note the corresponding anode current in micro-ammeter. Note these readings in table (1) as shown a head. Take at least 10-12 readings for each set.

5. Repeat the experiment for different anode potentials say 3 volt, 4 volt etc. Note all the readings in the table given below.
6. Plot a graph between anode current I_a μ amp and solenoid current I_s amp for each fixed value of anode potential as shown in Fig.4. (Preferably use different symbols for different anode potential).The

intersection of the tangent to the sloping curve with the steady I_a value gives the critical solenoid current I_c corresponding to B_c.. Calculate B_c for each value of anode potential using equation (3).

7. Plot a graph between anode potential V and B_c^2 and from the slope of this calculate e/m using equation (7).

Observations and Tabulations:

(a) Constants for Solenoid:

1. Length of Solenoid (L) = 0.3m
2. Diameter of Solenoid($2R_s$) (D_s) = 0.065m
3. Total number of turns in solenoid (n) = As mentioned in the set up

(b) Constant for Anode:

Radius of Anode (R_a) = 0.3 cm

TABLE 1:

S.No.	Solenoid Current (I_s) amp	Anode Potential (V) in Volts			
		2.0 Volts	3.0 Volts	4.0 Volts	5.0 Volts
		I_a (μamp)	I_a (μamp)	I_a (μamp)	I_a (μamp)
1					
2					
3					
4					
5					
6					
..					
..					

TABLE 2:

S.No	Anode potential V (Volts)	Critical solenoid current Ic (from graph) (μ Amp)	Critical mag. Field B_c. $B_c = \mu_0 N I_c Cos\theta$ (Weber/m^2)	B_c^2 (Weber/m^2)^2	V/ B_c^2 Volt/(Weber/m^2)^2	e/m Coul/Kg
1						
2						
3						
4						
..						
..						

Calculations

(i) $\frac{e}{m} = \frac{8V}{R_a^2 B_c^2}$

(ii) Plot a graph V vs B_c^2. It will be a straight line find the slope of this line. Then find $\frac{e}{m} = \frac{slope}{R_a^2/8}$ C/kg.

Result :

The experimentally observed and standard values of e/m are as follows

1. e/m (Experimental from calculation) =………………………………
2. e/m (Experimental from graph)=……………………………
3. e/m (standard)= 1.7589×10^{11} C/Kg.

Calculate maximum permissible error.

Precautions :

1. The readings should be taken
2. Graph should be plotted smoothly and the tangents should be drawn at appropriate positions.
3. Stray electric and magnetic field must be eliminated.