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EXPERIMENT-2

The ratio of e and m by Thompson Method

Aim: To determine the value of specific charge of an electron by the Thompson Method.

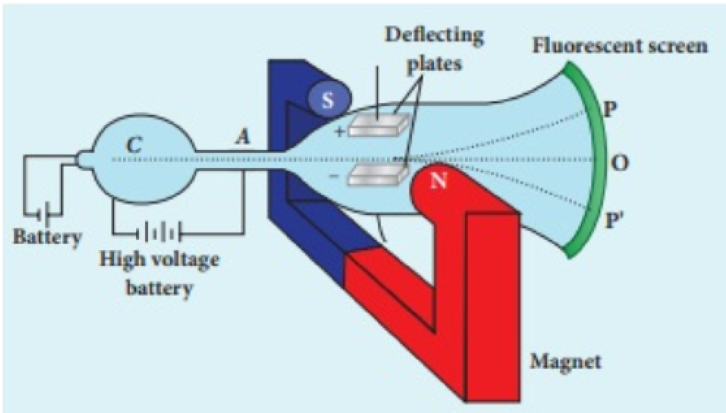
Apparatus:

- Cathode Ray Tube [C.R.T] mounted on a stand,
- e/m Power supply for C.R.T with a voltmeter to measure the deflecting voltage,
- Wooden bench having two arms fitted with scales to measure the distance of the bar magnet from C.R.T,
- Magnetometer(Compass) with a special stand for compass, this is also mountable in the middle of the wooden bench,
- Pair of bar magnets

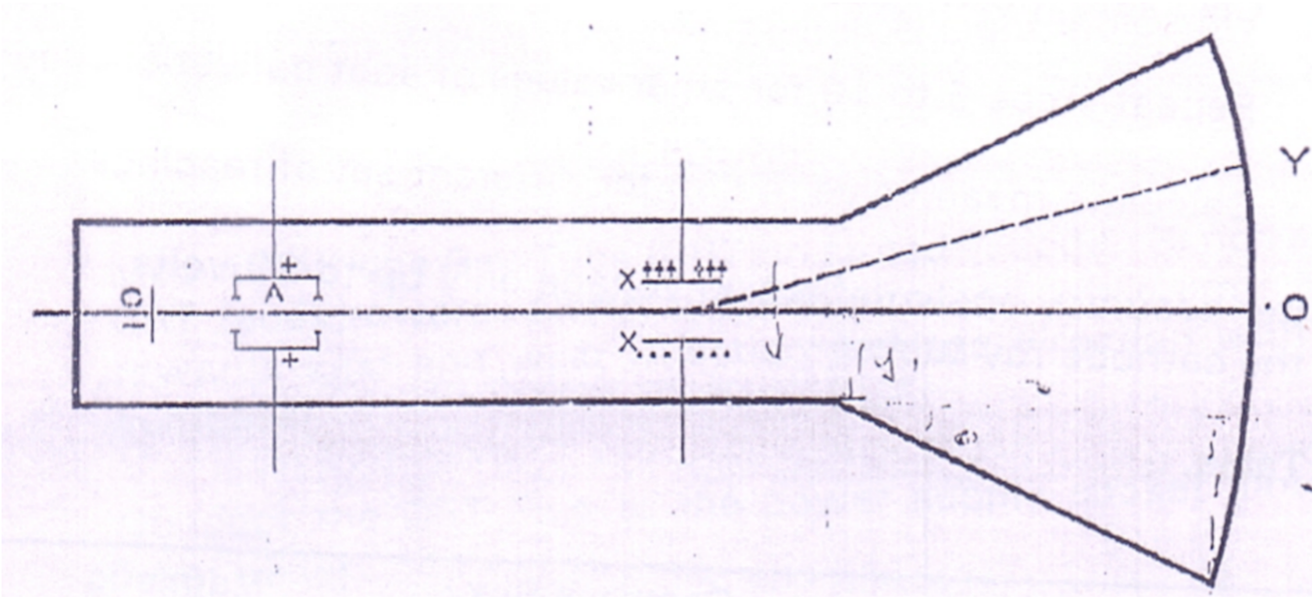
Theory:

Cathode Ray Tube (CRT) consists of three basic components-

1. Electron Gun- FF is a filament that when heated emits electrons. G (control grid) carries a negative charge, so sends out a beam of electrons which are accelerated by the anodes.
2. Deflecting System- This system deflects the beam of electrons either electronically or magnetically.
3. Fluorescent Screen- When the beam impinges on it, a spot is produced.



The value of e/m is independent of the nature of gas and material of the cathode of the discharge tube which indicated that electrons are fundamental of all materials. The presently accepted value of e/m is 1.7×107 e.m.u/gm.



<u>Working Formula-</u>

$$\frac{q}{m} = \frac{yV}{B^2 k}\ C/kg$$

$$B = B_H \tan\theta$$

where -

e/m = specific charge of an electron

e = charge of an electron

m = mass of an electron

y = deflection of the spot produced by magnetic field B

V = Voltage required to neutralize the deflection y

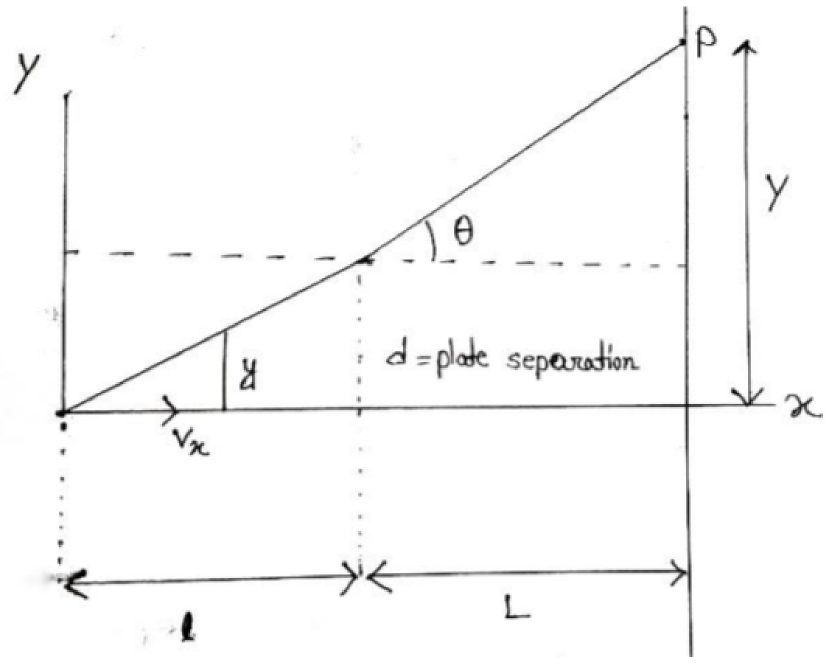
k = Constant for the C.R.T, i.e,

L = Distance of the screen from the edges of the plates

l = Length of deflection plate

B_H = Horizontal components of the earth's magnetic field = 0.38×10^{-4} T

θ = deflection produced in the magnetometer compass box



Total y-displacement is given by-

$$y = \frac{qEl}{mv_x^2}\left(L + \frac{l}{2}\right)$$

$$\frac{q}{m} = \frac{yv_x^2}{El(L+\frac{l}{2})} \qquad — 1$$

Now, applying magnetic field under undeflected conditions,

$$Bqv_x = Eq$$

$$\Rightarrow v_x = \frac{E}{B} \qquad — 2$$

Now, substituting equation-2 in equation-1, we get-

$$\frac{q}{m} = \frac{yE^2}{B^2El(L+\frac{l}{2})} = \frac{yE}{B^2l(L+\frac{l}{2})}$$

We also know $E = \frac{V}{d}$ where V is the applied voltage.

Therefore, we have arrived at the following-

$$\frac{q}{m} = \frac{yV}{B^2ld(L+\frac{l}{2})} = \frac{yV}{B^2k}$$

where $k = ld(L + \frac{l}{2})$

Observations:

- $l = 25\ mm$
- $d = 4\ mm$
- $L = 140\ mm$
- Least count of voltmeter = 2 V
- Least count of y-deflection scale = 1 mm
- Least count of compass = 1°

Table-1: Determination of e/m

Sl. No.	Applied voltage (V)	Spot deflection y (cm)	Deflection Compass needle θ (degree)	$K = ld\left(\frac{l}{2} + L\right)$	$B = B_H \tan tan\ (\theta)$	$\frac{e}{m} = \frac{Vy}{KB^2}$ (C/kg)
01	19	-1.4	83°	$152.5\times10^{-7}m^3$	$30.9\times10^{-5}T$	$1.829\times10^{11}C/kg$
02	14	-0.9	80°	$152.5\times10^{-7}m^3$	$21.5\times10^{-5}T$	$1.787\times10^{11}C/kg$
03	10	-0.7	77°	$152.5\times10^{-7}m^3$	$16.4\times10^{-5}T$	$1.706\times10^{11}C/kg$
04	8	-0.5	73°	$152.5\times10^{-7}m^3$	$12.4\times10^{-5}T$	$1.705\times10^{11}C/kg$
05	-8	0.6	74°	$152.5\times10^{-7}m^3$	$13.2\times10^{-5}T$	$1.806\times10^{11}C/kg$
06	-10	0.8	78°	$152.5\times10^{-7}m^3$	$17.8\times10^{-5}T$	$1.655\times10^{11}C/kg$
07	-14	1.0	81°	$152.5\times10^{-7}m^3$	$23.9\times10^{-5}T$	$1.607\times10^{11}C/kg$

08	-19	1.5	83°	$152.5\times10^{-7}m^3$	$30.9\times10^{-5}T$	$1.957\times10^{11}C/kg$

Calculation:

The average value of e/m is given by,

$$\left(\frac{1.829\times10^{11}+1.787\times10^{11}+1.706\times10^{11}+1.705\times10^{11}+1.806\times10^{11}+1.655\times10^{11}+1.607\times10^{11}+1.957\times10^{11}}{2}\right)$$

$= 1.756\times10^{11}\ C/kg$

Error Analysis:

Working Formula-

$$\frac{q}{m} = \frac{yV}{B^2k}\ C/kg$$

$$B = B_H\ tan\theta$$

$$\frac{\Delta\left(\frac{e}{m}\right)}{\frac{e}{m}} = \frac{\Delta V}{V} + \frac{\Delta y}{y} + \frac{\Delta\theta}{\tan tan\ \theta} = \frac{\Delta V}{V} + \frac{\Delta y}{y} + \frac{4\Delta\theta}{\sin sin\ 2\theta}$$

For maximizing the error here θ is considered 73° and corresponding V = 8 Volts and $|y|$ = 0.5cm, then we have -

$$\frac{\Delta\left(\frac{e}{m}\right)}{\frac{e}{m}} = \frac{\Delta V}{V} + \frac{\Delta y}{y} + \frac{\Delta\theta}{\tan tan\ \theta} = \frac{2}{8} + \frac{0.1}{0.5} + \frac{4\times\frac{\pi}{180}}{\sin(sin\ 2\times73)}$$

$$\frac{\Delta\left(\frac{e}{m}\right)}{\frac{e}{m}} = 0.574$$

$$\frac{\Delta\left(\frac{e}{m}\right)}{\frac{e}{m}}\times100 = 57.4\ \%$$

∴, The percentage error in e/m is 57.4%

$$\frac{\Delta\left(\frac{e}{m}\right)}{\frac{e}{m}} = 0.574$$

$$\Delta\left(\frac{e}{m}\right) = 0.574\ \times\left(\frac{e}{m}\right)$$

The average value of e/m is $1.756\times10^{11}\ C/kg$

$$\Delta\left(\frac{e}{m}\right) = 0.574 \times 1.756\times10^{11} = 1.007944\times10^{11} C/kg$$

$$\Delta\left(\frac{e}{m}\right) = 1.007944\times10^{11} C/kg \approx 1.008\times10^{11} C/kg$$

∴, The ratio of e/m by Thompson Method is $(1.756 \pm 1.008)\times10^{11} C/kg$

The value of the charge of an electron by the Thompson Method is given by-

$(9.109\times10^{-31}$ kg$) \times (1.756\times10^{11}$ C/kg$) = 1.5995 \times10^{-19}$ C $\approx 1.600\times10^{-19}$ C.

∴, The value of the charge of an electron by the Thompson Method is 1.600×10^{-19} C.

Results:

1. The ratio of e/m by Thompson Method is $(1.756 \pm 1.008)\times10^{11} C/kg$
2. The percentage error in e/m is 57.4%
3. The value of the charge of an electron by the Thompson Method is 1.600×10^{-19} C

Precaution:

1. Zero error must be noted in the measuring instruments.
2. To reduce statistical error in measurements, at least 3-5 readings must be taken.
3. Parallax and back-lash errors during measurement must be avoided.
4. The spot on the screen should be allowed to remain at a given position on the screen for a long time.
5. Ensure all the connections do not have any loose or open contacts.
6. High voltage is used to power this apparatus. All assembly steps must be completed before plugging in or turning on the power supply. It is also important to observe all cautions listed with your power supply.

Discussion:

1. According to classical electrodynamics, when two particles with the same mass-to-charge ratio are subjected to the same electric and magnetic fields, they will move in the same path in a vacuum.
2. A cathode-ray tube (CRT) is a vacuum tube in which an electron beam, deflected by applied electric or magnetic fields, produces a trace on a fluorescent screen. The function of the cathode ray tube is to convert an electrical signal into a visual display.
3. Uses of Cathode Ray Tube-
    a. Used as a most popular television (TV) display.
    b. X-rays are produced when fast-moving cathode rays are stopped suddenly.
    c. The screen of a cathode ray oscilloscope, the monitor of a computer, are coated with fluorescent substances. When the cathode rays fall off the screen pictures are visible on the screen.
4. From this experiment, J.J Thomson concluded that-
    a. Rays are basically negatively charged particles present or moving around in a set of a positive charge. This theory further helped physicists in understanding the structure of an atom.
    b. Another significant observation that was made was that the characteristics of cathode rays or electrons did not depend on the material of electrodes or the nature of the gas present in the cathode ray tube. Thus, indicating that the electrons are in fact the basic constituent of all the atoms.
    c. Most of the mass of the atom and all of its positive charges are contained in a small nucleus, called a nucleus. The particle which is positively charged is called a proton. The greater part of an atom's volume is empty space.
    d. The number of electrons that are dispersed outside the nucleus is the same as the number of positively charged protons in the nucleus. This explains the electrical neutrality of an atom as a whole.