ATOMIC PHYSICS

1.SPECIFIC CHARGE AND CHARGE OF AN ELECTRON

POINTS TO REMEMBER

1. The study of discharge through gases at low pressure led to the discovery of electron.
2. At a low pressure of about 0.01 mm and at a high voltage of about 20,000V some invisible radiation called cathode rays travel from cathode towards anode. These are fast moving electrons.
3. **JJ THOMSON EXPERIMENT:**

   a. An electron beam is subjected to mutually perpendicular (crossed) electric and magnetic fields and the deflection of the electron beam is studied.
   b. Both electric and magnetic fields are perpendicular to the motion of the electron beam.
   c. The force on the electron beam due to the magnetic field is given by $F_M = Bev$ where e is the magnetic field of induction and v is the velocity of the electron.
   d. The force on the electron beam due to the electric field is given by $F_e = Ee$ where e is the charge of the electron and E is the intensity of the electric field.
   e. When there is no deflection in the cathode ray beam in the presence of both electric and magnetic fields , then $V = \frac{E}{B} = \frac{V}{dB}$
   f. Also in a transverse electric field Ve = ½ mv^2 and $\frac{e}{m} = \frac{v^2}{2V}$

   Specific charge of electron, $\frac{e}{m} = \frac{E^2}{2VB^2}$ or $\frac{e}{m} = \frac{E^2}{B^2 r}$; r = radius of circular path.

   g. The value of specific charge is found to be1.759×10^{11}coulomb /Kg.
   h. To know that all the electrons produced in different methods are identical and to determine the mass of the electron from the knowledge of e/m and e.
   i. Of all fundamental particles the e/m of electron is maximum.
4. **Millikan's oil drop Experiment.**
   a. The charge of an electron is determined by studying the motion of a charged oil drop in both electric field and gravitational field.
   b. Let ρ be the density of oil drop and σ be the density of air.

   Weight of oil drop = mg = $\frac{4}{3}\pi r^3 \rho g$

   c. When oil drop falls with constant velocity V_T then, Force due to viscosity $F_v = 6\pi\eta rv$
   Where r = radius of oil drop and η = coefficient of viscosity of air medium
   d. Force due to Buoyancy of air$=\frac{4}{3}\pi r^3 \sigma g$.

e. The net weight of the drop is equal to the viscous force, then the drop falls down with a terminal velocity v_1.

$$\therefore \frac{4}{3}\pi r^3(\rho-\sigma)g = 6\pi\eta r v_1 \quad \Rightarrow r = \left(\frac{9\eta v_1}{2(\rho-\sigma)g}\right)^{1/2}$$

f. Now an electric field of intensity E is applied between the plates in the downward direction so that the drop is now made to move up with a terminal velocity v_2.

g. The net force acting on the drop is zero

$$w + F_V = F_E + F_B$$

Or $$\frac{4}{3}\pi r^3 \rho g + 6\pi\eta r v_2 = Eq + \frac{4}{3}\pi r^3 \sigma g$$

Or vv $$\frac{4}{3}\pi r^3(\rho-\sigma)g + 6\pi\eta r v_2 = Eq$$

$$\therefore q = \frac{6\pi\eta r(v_1+v_2)}{E}$$

Or $$q = \frac{6\pi\eta(v_1+v_2)}{E}\sqrt{\frac{9\eta v_1}{2(\rho-\sigma)g}}$$

h. The result of Millikan's oil drop experiment is that the values of charge (q) present on the oil droplet are always integral multiples of a common value e, such that q = ne, where n is an integer and e is the elementary charge equivalent to that of an electron. The charge of an electron is $1.60217733\times10^{-19}C$

LONG ANSWER QUESTIONS

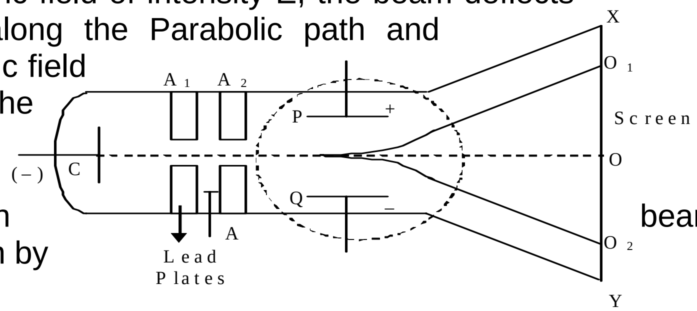
1. Define Specific charge? Describe Thomson's experiment to determine e/m of an electron with relevant theory.

A: **Specific Charge**: The ratio between the charge of an electron and its mass is known as the specific charge of an electron.

Principle An electron beam is subjected to mutually perpendicular (crossed) electric and magnetic fields and the deflection of the electron beam is studied.Both electric and magnetic fields are perpendicular to the motion of the electron beam.

Description: The experimental arrangement consists of a discharge tube with a cathode C which emits cathode rays normal to it.The pressure of the gas inside the discharge tube is about 0.01mm of Hg and the P.D across the electrodes is about 20,0000V. Then cathode rays are emitted from the cathode.A is the anode and A_1, A_2 are the lead plates with small holes to get a narrow beam of cathode rays.At some distance from the anode two condenser plates P & Q are arranged. Let V be the potential difference between them and d is the separation between the plates.At the position of the electric field, a magnetic field of induction B can also be produced by using a solenoid. The magnetic field is represented by dotted circle.XY is the fluorescent screen.

Procedure In the absence of both electric and magnetic fields, the cathode ray travels straight and strikes the fluorescent screen at O.When the cathode ray beam is subjected to an electric field of intensity E, the beam deflects towards the positive plate along the Parabolic path and strikes the screen at O_1.Electric field is perpendicular to the path of the electron beam in the plane of the diagram downwards.



The force on the electron beam due to the electric field is given by

$$F_e = E\,e$$

Where e = charge of the electron. Now electric field is removed and a uniform magnetic field of induction B is applied in the same region of the electric field. The magnetic field is perpendicular to both electric field and path of the electron beam and it is into the diagram. Hence the electron beam is deflected along an arc of a circle which is opposite to that produced by the electric field and strikes the screen at O_2. The force on the electron beam due to the magnetic field is given by $F_M = Bev$ Now both electric and magnetic fields are applied simultaneously on the electron beam and the deflection in the electron beam is made zero, i.e., the force due to the electric and magnetic fields are numerically equal.

$$F_e = F_M \quad \text{and} \quad E_e = Bev$$

$$V = \frac{E}{B} = \frac{V}{dB} \ldots\ldots\ldots(1)$$

This is the velocity of the electron beam in the crossed electric and magnetic fields when there is no deviation or deflection.

The work done in accelerating the electron through a potential difference V is given by $W = Vq = Ve$

This is used to increase the kinetic energy of the electron from zero to ½ mv^2.

$\therefore$ Ve = ½ mv^2 and $\frac{e}{m} = \frac{v^2}{2V}$

From equation (1) $\frac{e}{m} = \frac{E^2}{2VB^2}$

By substituting the values of E, V, B in the above equation, the specific charge of an electron can be determined. It is found to be 1.759×10^{11} coulomb /Kg.

SOLVED PROBLEMS

1. Calculate the velocity of electrons accelerated by a potential difference of $1.6\times10^4 V$. The charge of the electron is $1.6\times10^{-19} C$ and mass is $9.11\times10^{-31} kg$.

Sol: $e = 1.6\times10^{-19}\,C$, $m = 9.11\times10^{-31}\,kg$, $v = 10^4 V$

$$eV = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{\frac{2eV}{m}} \Rightarrow v = \sqrt{\frac{2\times1.6\times10^{-19}\times10^4}{9.11\times10^{-31}}} = 5.93\times10^7\,ms^{-1}$$

2. **An electron enters into a magnetic field of induction $1\times10^{-2}\,T$ with velocity $1\times10^{7}\,m/s$ and deflects into a circular path of radius $6\times10^{-3}\,m$. Find the specific charge of the electron.**

Sol: $Be\,v = \frac{mv^2}{r} \Rightarrow \frac{e}{m} = \frac{v}{rB}$

R $= 6\times10^{-3}\,m$; v $= 1\times10^{7}\,m/s$; B $= 1\times10^{-2}\,T$.

$$\frac{e}{m} = \frac{1\times10^{7}}{6\times10^{-3}\times1\times10^{-2}} 1.67\times10^{11}\,C\,kg^{-1}$$

UNSOLVED PROBLEMS

1. **The voltage across the electrons of a cathode ray tube is 500V. Calculate the speed of the electrons .**

Sol: V = 500 V

e/m of electron $= 1.76\times10^{11}\,C/kg$.

$$\therefore Ve = \frac{1}{2}m\upsilon^2 \quad \Rightarrow \frac{1}{2}m\upsilon^2 = eV$$

Velocity $(\upsilon) = \sqrt{\frac{2eV}{m}} = \sqrt{2\times500\times1.76\times10^{11}} = 1.33\times10^{7}\,m/s$

2. **An electron at rest is accelerated through the potential difference applied across anode and cathode of 200V. If the velocity of the electron is** $8.4\times10^{6}\,ms^{-1}$ find its e/m.

Sol: V = 200 V ; $\upsilon = 8.4\times10^{6}\,m/\sec$ **;** e/m value = ?

$$Ve = \frac{1}{2}m\upsilon^2 \Rightarrow e/m = \frac{V^2}{2\upsilon} = \frac{8.4\times8.4\times10^{12}}{2\times200}$$

$$\therefore \frac{e}{m} = 1.764\times10^{11}\,C/kg$$

3. **Calculate the velocity of the electrons which is accelerated by the potential difference of 10,000 V. Given charge of the electron is** $1.6\times10^{-9}\,C$ and mass is $9.11\times10^{-31}\,Kg$.

Sol: V = 10, 000 V ; $e = 1.6\times10^{-19}\,C$; $m = 9.11\times10^{-31}\,kg$; $\upsilon = ?$

$$\therefore V.e = \frac{1}{2}m\upsilon^2 \Rightarrow \upsilon = \sqrt{2V.\frac{e}{m}}$$

$$\therefore \upsilon = \sqrt{\frac{2\times 10,000\times 1.6\times 10^{-19}}{9.11\times 10^{-31}}} = 5.93\times 10^{7}\ m\sec^{-1}$$

4. **An electron beam moving with a speed of $2.5\times 10^{7}\ ms^{-1}$ enters into the magnetic field directed perpendicular to its direction of motion. The magnetic induction of the field is $4\times 10^{-3}\ Wb/m^{2}$. Find the intensity of an electric field applied so that the electron is un-deflected due to the magnetic field.**

Sol: $\upsilon = 2.5\times 10^{7}\ m/\sec$; $B = 4\times 10^{-3} Wb/m^{2}$; E = ?

When un-deflected , $\upsilon = E/B \Rightarrow E = \upsilon.B.$

$\therefore E = 2.5\times 10^{7}\times 4\times 10^{-3} = 10^{5}\ N/C$

5. **A mono-energetic electron beam with speed of $5.2\times 10^{6} ms^{-1}$ enters into the magnetic field of induction $3\times 10^{-4} T$ directed normal to the beam. Find the radius of the circle traced by it.(Given $e/m = 1.76\times 10^{11} C\ Kg^{-1}$).**

Sol: $\upsilon = 5.2\times 10^{6}\ m/\sec$; $B = 3\times 10^{-4}\ T$; $e/m = 1.76\times 10^{11}\ C/Kg^{-1}$.

But, $\frac{m\upsilon^{2}}{r} = Be\upsilon \Rightarrow r = \frac{m\upsilon}{Be}$

$$\therefore r = \frac{5.2\times 10^{6}}{3\times 10^{-4}\times 1.76\times 10^{11}} = 0.098\ m$$

6. **Calculate the force experienced by a moving electron which is entering into a condenser having its plates 0.1 m apart and potential difference of 300V. The electric field is perpendicular to the motion of the electron.**

Sol: Separation between the plates d=0.1 m

Potential on plate s$V_1 = 300V$

Intensity of electric field $E = \frac{V_1}{d} = \frac{300}{0.1} = 3000\ V/m$

Charge on electron $e = 1.6\times 10^{-19} C$

Force on electron electric field F = E.e

$\therefore F = 3000\times 1.6\times 10^{-19} = 4.8\times 10^{-16} N$

<u>ASSESS YOURSELF</u>

1. We know that cathode rays are invisible. If so how are they discovered?

A. Basing on the phenomenon of fluorescence.

2. Among the following, which one has lowest specific charge – Proton, α-particle, p-particle?

A. α-particle.

3. What is the ratio of velocities of a proton, a deuteron and an α-particle when they are accelerated by same potential difference.

A. $\sqrt{2}:1:1$

4. Can the specific charge of an electron change with speed?

A. Yes. If the speed of the electron increases, its mass increases, charge being the same. Hence the specific charge of an electron decreases with the increase of speed of the electron.

5. If the pressure in the discharge tube is made as low as nearly zero, does conduction take place?

A. No.

6. Is it possible to accumulate a charge of $4.0\times10^{-19}C$ on a body?

A. No. Because it is not an integral multiple of the charge of the electron.