# Gaseous Discharge

## Gaseous Discharge

- At NTP, air (gases) act as insulators. No free electrons or ions are created to pass electricity through gases.
- When low pressure & high potential different is maintained, air get ionized, many free electrons or ions are created to pass electricity through gases. Now, gas medium act as the conductors.
- In case of an insulators, energy gap between valence band and conduction band is 3 eV or more.
- The di-electric strength of air at NTP is $3 \times 10^6$ volt/m.
- Gases become conducting when pressure is about 0.01 mm of Hg.
- The passage of electricity through a gas medium at low pressure & high potential is called electric discharge.

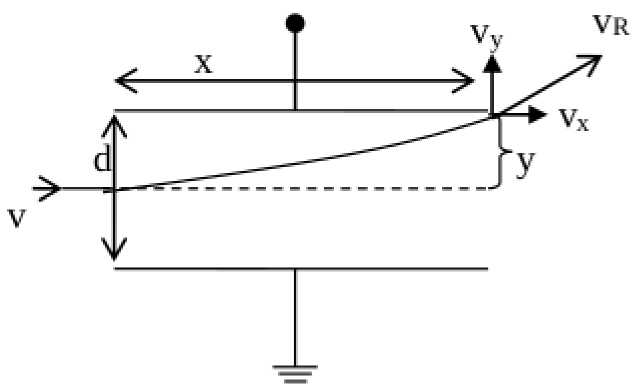
## Cathode rays

Cathode rays are stream of invisible particles originated from cathode and extended towards anode at low pressure 0.01 mm of Hg & high p.d. about 10 -15 kV between the two electrodes of discharge tube.

- Cathode rays are independent with the nature of gas and their direction of propagation is not affected by the position of the anode. Actually, cathode rays are the group of -vely charged particles, called electrons.
- Cathode rays were discovered by Sir William Crooke.
- Velocity of cathode rays is 1/10$^{th}$ of velocity of light in vacuum.
- They are chargeful, possess mass and deflected by fields.
- They can ionize gas, excite fluorescent, penetrate this sheet of matter.
- Mass of an electron is 9.1 $\times$ 10$^{-31}$ kg & charge of an electron is -1.6 $\times$ 10$^{-19}$ C.

## Motion of electron in a uniform electric field

If an electron having basic charge e, projected $\mathrm{e}^-$ into the region of uniform electric field $(\mathrm{E})$, midway between the plates, electron feel a force $(\mathrm{eE})$ and possess a uniform acceleration then after accelerated towards +ve charged plate in parabolic path, strike on upper spot of the screen, complete vertical displacement $\mathrm{y}$.




In vertical motion,

$$F = eE$$
$$ma = eE$$
$$a = \frac{eE}{m}\left(E = \frac{V}{d}\right)$$

Acceleration gain by $\mathrm{e}^-$ during its motion is:

$$a = \frac{eV}{md} \ldots\ldots (1)$$

Again,

$$s = ut + \frac{1}{2}at^2$$

$$X = vt + 0$$

$$t = \frac{X}{v} \ldots\ldots (2)$$

We project electron horizontally in electric field with uniform velocity $\mathrm{v}$, therefore acceleration in horizontal motion is zero.

In vertical motion,

$$s = ut + \frac{1}{2}at^2$$

$$y = \frac{1}{2}at^2$$

$$y = \frac{1}{2}\frac{eV}{md}\frac{x^2}{v^2} \ldots\ldots\ldots (3)$$

We have,

$$x^2 = \left(\frac{2mdv^2}{eV}\right) y \ldots\ldots (4)$$

Equation 4 represents equation of parabola.

- Hence, motion of electron in a uniform electric field is always parabolic.
- Angle of deflection is,

  $$\tan\theta = \frac{v_y}{v_x}$$

  $$\theta = \tan^{-1}\left(\frac{v_y}{v_x}\right) \ldots\ldots\ldots (5)$$

- The path of an $\mathrm{e}^-$ in a uniform electric field is parabolic in nature.

Motion of $e^-$ in a uniform magnetic field

- Force on $e^-$ in a uniform magnetic field of strength $B$ is:

  $$F_m = Bev\ \sin\theta$$

  If an $e^-$ enters normally into the magnetic field, force experience is maximum. Therefore,
  When $\theta = 90^\circ,\ F_{max} = Bev$ (Lorentz Force)

  $$F_{max} = Bev \ldots\ldots (1)$$

- Centripetal force $= \frac{mv^2}{r} \ldots\ldots (2)$

- Electrons are in circular path, only when:

  $$F_m = F_c$$

  $$Bev = \frac{mv^2}{r}$$

  $$r = \frac{mv}{Be} = \frac{v}{B(e/m)} = \frac{mv}{Be} = \frac{P}{Be} \ldots (3)$$

  Here,

  $v \rightarrow$ const.
  $B \rightarrow$ const.
  $e/m \rightarrow$ const.

  Hence, $r =$ constant.

- In a uniform magnetic field, the motion and path of an $e^-$ is circular.
- Time period for an $e^-$ to complete one revolution is :

$$T = \frac{2\pi}{B(e/m)} \ldots\ldots (4)$$

- Frequency of revolution is :

$$f = \frac{1}{2\pi} B(e/m) \ldots\ldots (5)$$

Motion of electron in cross-field

- When a uniform electric & magnetic field act perpendicular to each other, force gain by $e^-$ in electric field is balanced by the force gain by $e^-$ in magnetic field.

- In cross-field, electron neither deflected in parabolic path due to electric field nor deflected in curved path due to magnetic field but electron again moves along its straight path.

- In cross-field,

$$F_e = F_m$$

$$eE = Bev$$

$$v = E/B \qquad E = \frac{V}{d}$$

$$v = \frac{V}{Bd} \cdots\cdots\cdots (1)$$

Here,
$V \rightarrow$ potential diff. is constant.
$d \rightarrow$ separation distance between the plates is constant.
$B \rightarrow$ applied magnetic field during the experiment is constant.

Therefore, velocity $(v)$ is constant.

- In cross-field, the motion & path of an $e^-$ is straight line.

J.J. Thomson's experiment

- In 1897, J.J. Thomson performed the experiment.

- To determine specific change of an electron.

- Specific charge means charge to mass ratio of an $e^-$.

- This experiment based on principle of cross-field.

- Specific charge of an electron is:

$$e^-/m = \frac{V}{2B^2d^2} \quad \text{(from electric field)}$$
$$e^-/m = \frac{V}{B^2d \cdot r} \quad \text{(from magnetic field)}$$
$$e^-/m = 1.76 \times 10^{11} \ C/kg$$

- Specific charge of H-atom (proton) is :

$$\frac{e}{m_P} = \frac{1.6 \times 10^{-19}}{1.67 \times 10^{-27}} = 9.6 \times 10^7 \ C/kg$$

- Specific charge of $\alpha$-particle (Helium nucleus) is:

$$\frac{q_\alpha}{m_\alpha} = \frac{2e}{4m_P} = 4.8 \times 10^7 \ C/kg$$

- Specific charge of $\beta$ radiation is equal to specific charge of an $e^-$.
- Specific charge of neutron is zero.

Positive rays or Canal rays

- Positive rays discovered by Goldstein.
- Positive rays are produced in a discharge tube with the help of perforated cathode.
- The presence of isotopes makes the charged particles in the positive rays to have different velocities.
- The lightest +vely charged particle is called proton.
- The instrument used for +ve rays analysis is called mass spectrograph.

Millikan's oil drop experiment

- Robert Andrew Millikan first measured the terminal velocity of a spherical oil drop through air.
- In 1914, R.A. Millikan's performed oil drop experiment to determine charge of an oil drop (charge of an $e^-$).
- This experiment based on principle of Stoke's theorem.
- The backward dragging force which resists the motion of fluids, is known as viscous force.
- Viscous force is

  $$F_v = 6\pi\eta rv \ldots\ldots (1)$$

  where,
  $\eta \rightarrow$ coefficient of viscosity
  $r \rightarrow$ radius of spherical oil drop
  $v \rightarrow$ terminal velocity of an oil drop in air

  - ### Without electric field:

    Wt. of an oil drop is:

    $$W = mg$$

    $$W = V\rho g$$

    $$W = \frac{4}{3}\pi r^3 \rho g(\downarrow) \ldots\ldots (1)$$

    Acting downward.

    Upthrust exerted by air to displace equal volume of an oil drop. Upthrust is:

    $$U = \frac{4}{3}\pi r^3 \sigma g(\uparrow) \ldots\ldots (2)$$

    Acting upward.

    Resultant wt. of an oil drop is:

    $$R.W. = W - U$$
    $$R.W. = \frac{4}{3}\pi r^3 (\rho - \sigma)g \ (\downarrow) \ldots\ldots (3)$$

    In equilibrium condition,

    $$R.W. = \text{Viscous force}$$
    $$\frac{4}{3}\pi r^3 (\rho - \sigma)g = 6\pi\eta rv_1$$

    Radius of spherical oil drop is:

    $$r = \sqrt{\frac{9\eta v_1}{2(\rho - \sigma)g}} \ldots\ldots (4)$$

- **With electric field:**

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

  $$ne = \frac{6\pi\eta r d}{V}(v_1 - v_2)\,.........\,(5)$$

  $$n = 1, \qquad e = -1.6 \times 10^{-19}\mathrm{C}$$

- Millikan's oil drop experiment deals about the quantization of electric charge.