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P.G.(Sem-IV) ~Dr. S. Roy

"Diffusion And Mobility of Charged Particles In Plasma"

In a confined plasma there will generally be a density or pressure gradient from the interior to the outside which will cause charged particle to collide one another. As a result of this collision, diffusion of charged particle starts. Because of low density, electron-electron or electron-ion collision can be neglected, but only collision between a neutral particle and either an electron or an ion is taken under consideration.

Suppose the charged particles in the plasma are continually colliding with a lattice of fixed collision centres. The particles are monoenergetic and density varies only along the x-axis. If $\frac{dn}{dx}$ is the rate of variation of particles along x-axis then the number of articles at a distance x from origine O will be

$$n = n_0 + \frac{dn}{dx}x \longrightarrow (1)$$

where, n_0 = particle density at origin O.
n = " " at x from O.

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If v is the random velocity and λ is the mean free path of the electron the collision frequency ν_c is given by $\nu_c = \frac{v}{\lambda}$ and hence the collisions per sec is given by

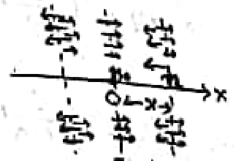

Fig 1

$$= n\nu_c$$
$$= \frac{v}{\lambda}n$$

If the velocity distribution is isotropic after collision then one third ($\frac{1}{3}$rd) of the particles will move along the x-axis and out of these half will move in positive direction and half in the negative direction. Hence the rate at which particles will move along the x-axis towards right will be

$$\frac{1}{6}\left(\frac{v}{\lambda}n\right)$$

The probability that a particle colliding at x will reach O without collision is $e^{-x/\lambda}$, then the charged particle current dI at O, along x-axis towards right for distance dx is given by

$$dI = \frac{v}{6\lambda}n\,e^{-x/\lambda}dx$$

Now, the net current will be the difference after integration, ~~considering~~ from $-\infty$ to $+\infty$ (i.e. for both direction right & left)

$$I = \int_{-\infty}^{+\infty} dI = \int_{-\infty}^{\infty} \frac{v}{6\lambda}n\,e^{-x/\lambda}dx$$

$$\therefore I = \int_{-\infty}^{0} \frac{v}{6\lambda} n e^{-x/\lambda} dx + \int_{0}^{\infty} \frac{v}{6\lambda} n e^{-x/\lambda} (-dx)$$

$$= \int_{-\infty}^{0} \frac{v}{6\lambda} n e^{-x/\lambda} dx - \int_{0}^{\infty} \frac{v}{6\lambda} n e^{-x/\lambda} dx$$

putting the value of n from eq^n(1) in above equation, we have.

$$I = \int_{-\infty}^{0} \frac{v}{6\lambda}\left(n_0 + \frac{dn}{dx}x\right) e^{-x/\lambda} dx - \int_{0}^{\infty} \frac{v}{6\lambda}\left(n_0 + \frac{dn}{dx}x\right) e^{-x/\lambda} dx$$

$$= \int_{-\infty}^{0} \frac{v}{6\lambda} n_0 e^{-x/\lambda} dx + \frac{v}{6\lambda}\int_{-\infty}^{0} \frac{dn}{dx} x e^{-x/\lambda} dx$$

$$- \frac{v}{6\lambda}\int_{0}^{\infty} n_0 e^{-x/\lambda} dx - \frac{v}{6\lambda}\frac{dn}{dx}\int_{0}^{\infty} x e^{-x/\lambda} dx$$

$$= \frac{v}{6\lambda}\frac{dn}{dx}\left[\int_{-\infty}^{0} x e^{-x/\lambda} dx - \int_{0}^{\infty} x e^{-x/\lambda} dx\right]$$

$$\left(\because \int_{-\infty}^{0} n_0 e^{-x/\lambda} dx = \int_{0}^{\infty} n_0 e^{-x/\lambda} dx = n_0\lambda\right)$$

$$= \frac{v}{6\lambda}\frac{dn}{dx}(-2\lambda^2)$$

$$= -\frac{v\lambda}{3}\frac{dn}{dx} \longrightarrow (2)$$

Now from the definition of diffusion constant

$$I = -D\frac{dn}{dx} \longrightarrow (3)$$

On comparing eq^n (2) and (3), we have,

$$D = \frac{v\lambda}{3} \longrightarrow (4)$$

Eq^n(4) is the expression for diffusion. The mobility coefficient μ is defined as

$$\mu = \frac{e}{mv} = \frac{e\lambda}{mv} \longrightarrow (5) \quad \left[\because v = \frac{v}{\lambda} \text{ and } v = \frac{3D}{\lambda} \text{ from eq}^n(4)\right]$$

$$= \frac{e\lambda}{3mD}$$

And also, $\frac{D}{\mu} = \frac{1}{3}\frac{mv^2}{e}$

$$= \frac{2}{3e}\left(\frac{1}{2}mv^2\right)$$

$$= \frac{2}{3e}KT \rightarrow (6)$$

For electron, $\frac{D_e}{\mu_e} = \frac{2}{3e}KT_e$

and for ion, $\frac{D_i}{\mu_i} = \frac{2}{3e}KT_i$ } (7)

Where T_e and T_i are the electron temperature and ion temperature respectively. These eq^n (6) and (7) are known as "Einstein's relation". As $D_e = \frac{\lambda_e v_e}{3}$ and $D_i = \frac{\lambda_i v_i}{3}$ where λ_e is the mean free path for electron neutral atom collision and λ_i is the mean free path for ~~electron~~

ion neutral atom collision. As at a given temperature $v_e >> v_i$ and hence electrons will diffuse more quickly than the ions. As a result, a charge separation will take place and a space charge electric field will be established.