Plasma Physics

MSc. Physics Semester 2

Paper - MPHY CC6

Unit 5

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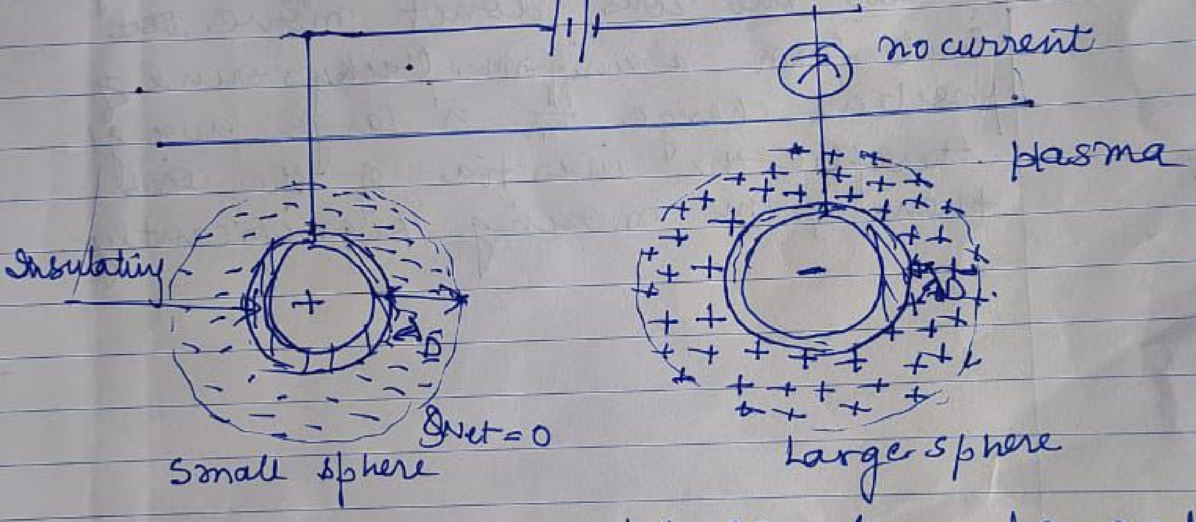
Plasma Physics

Debye Sheiding

Debye Sheiding effect is the a characteristic of all plasma. The Debye length is an important parameter for the description of plasma. It is a measure of length or distance in plasma the influence of the electric field of an individual charged particle due to other charged particle inside the plasma. The charged particles arrange themselves in such a way and form a shield called Debye sphere with a radius equal λ_D to Debye radius/length.



Let us suppose two charged balls have been inserted inside a plasma. The balls would attract particles of opposite charges and immediately a cloud of ions would surrounded by negative ball and electrons would surrounded by the positive ball on the surface of balls, potential is maintained. Then the shielding would be formed and no electric field would be present in the body of plasma outside the surface of cloud. In plasma no current is flow because charge is shield. Dimension of electron cloud is less than ion cloud. The shield of electrostatic field is a consequence of the collective behaviour of the plasma behaviour

Ion electron mass ratio $\frac{M}{m}$ is infinite so that the ions donot move, but form a uniform background of positive charge $\frac{M}{m}$ is large enough therefore the inertia of the ions them from moving significantly.

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From Gauss's law.

$$\vec{\nabla}\cdot\vec{E} = \frac{\rho}{\epsilon_0}$$

$\rho = ne(n_i - n_e)$

$n_i = n_e$ no of ions per unit volume

$$\boxed{\nabla^2\phi = -\frac{\rho}{\epsilon_0}}$$

~~Let us~~ Since the positive charged Q attracts the e^- charged particles and repels the e^+ (ions), the number densities of the electrons $n_e(r)$ and of the ions $n_i(r)$ will be slightly different near the origin. whereas at large distances ~~from~~ electrostatic potential vanishes i.e. $n_e(\infty) = n_i(\infty) = n_0$

According to Boltzmann function

$$n_e = n_0 \exp\left[\frac{e\phi}{KT}\right]$$

$$n_i = n_0 \exp\left[-\frac{e\phi}{KT}\right]$$

$$\nabla^2\phi = -\frac{e(n_i - n_e)}{\epsilon_0}$$

n_0 - number of particle per unit volume

Let us assume that number of ions are fixed. Plasma is quasineutral behaviour

$n_e = n_i$.

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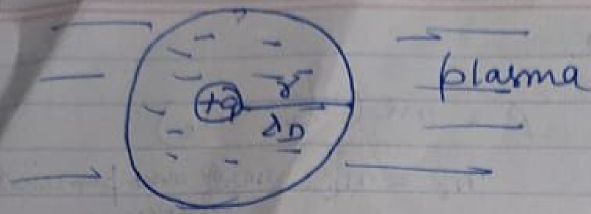

$$\phi = \frac{1}{4\pi\epsilon_0}\frac{q}{r} \quad \text{when } r \gg \lambda_D$$

when $r \gg \lambda_D$

~~qo~~ $q = 0$, $\phi = 0$

$$\nabla^2\phi = -\frac{e}{\epsilon_0}(n_i - n_e)$$

$$= -\frac{e}{\epsilon_0}\left[n_0 - n_0 \exp\frac{e\phi}{KT}\right]$$

$$\nabla^2\phi = -\frac{e n_0}{\epsilon_0}\left[1 - \exp\frac{e\phi}{KT}\right]$$

$e\phi \ll KT$ Potential energy is less than K·E

$$\exp\frac{e\phi}{KT} = 1 + \frac{(e\phi)}{KT} + \frac{(e\phi)^2}{KT}\frac{1}{2!}$$

$$= 1 + \frac{e\phi}{KT}$$

$$\therefore \nabla^2\phi = -\frac{e}{\epsilon_0}\left[n_0 - n_0\left\{1 + \frac{e\phi}{KT}\right\}\right]$$

$$= -\frac{n_0 e}{\epsilon_0}\left[1 - 1 - \frac{e\phi}{KT}\right]$$

$$\boxed{\nabla^2\phi = \frac{n_0 e^2\phi}{\epsilon_0 KT}}$$

Taking one dimensional equation (I)

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$$\nabla^2\phi = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

Let us assume

$$\phi = \phi_0 e^{-x/\lambda_D}$$

$$\frac{d\phi}{dx} = -\frac{1}{\lambda} e^{-x/\lambda_D}$$

$$\frac{d^2\phi}{dx^2} = \left(\frac{1}{\lambda}\right)^2 \phi_0 e^{-|x|/\lambda}$$

$$\frac{d^2\phi}{dx^2} = \left(\frac{n_0 e^2}{\epsilon_0 KT}\right)\phi \text{ where } \frac{ne^2}{\epsilon_0 KT} = \lambda_D$$

λ_D is Debye length.

This is the solution of [II] where ϕ_0 is the maximum potential at the surface of inserted charge in plasma

~~Boundary~~ $\phi = \phi_0 e^{-|x|/\lambda_D}$

Boundary condition in free charge

$x \Rightarrow 0 \Rightarrow \phi = \phi_0$ | satisfy the condition

$x \to \infty \Rightarrow \phi = 0$ |

$\cancel{x \Rightarrow \lambda_D \Rightarrow \phi =}$

~~We plot~~

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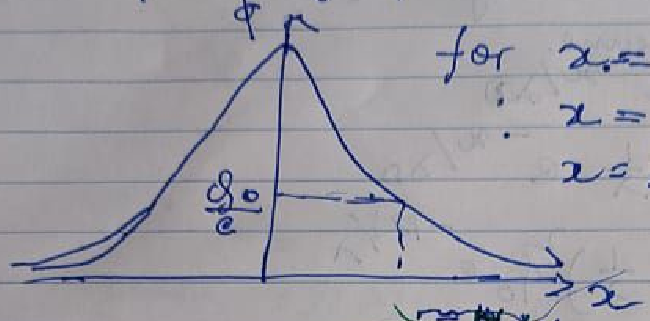
We plot a graph



for $x = 0 \Rightarrow \phi = \phi_0$
$x = \infty \Rightarrow \phi = 0$.
$x = \lambda_D \Rightarrow \phi = \phi_0/e$

$|x|/\lambda_D$

$$\phi = \phi_0 e^{-|x|/\lambda_D}$$

Debye length or Debye radius λ_D is the distance at which value of external potential, which inserted inside plasma $\frac{1}{e}$ times to its maximum value i.e λ_D is the length inside plasma after which external potential decreases much rapidly

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Books recommended

1. Introduction to Plasma Physics and controlled fusion
   — F. F. Chen
2. Fundamental of Plasma Physics
   — J. A. Bittencourt