Plasma Physics

MSc. Physics Semester 2

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Unit 5

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Plasma Oscillation

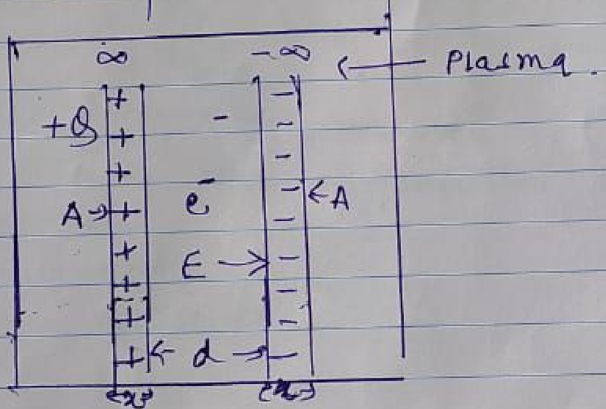
Plasma is a collection of electrons, ions and neutral particles. Plasma is quasineutral i.e $n_i \approx n_e$ and which exhibits collective behaviour.

Let us consider a small spherical region inside a plasma and suppose that a perturbation in the form of an excess of negative charge is introduced in this small region. The electric fields generate towards the centre in fig 1. Thereafter the electrons move outward due to spherical symmetric. Electrons gains kinetic energy than more electrons leave in spherical plasma. ~~Due to quasineutral behaviour of plasma.~~ an ~~ion excess~~ ions.

To restore the neutrality of the plasma by pulling electrons back to their original position. Then electrons oscillate due to inertia around their equivalent equilibrium position with some frequency known as plasma frequency. The oscillation is so fast ~~that~~ then ions donot have time to respond to the oscillating field.

For derivation for the plasma frequency ω_p we consider following assumptions
1. There is no magnetic field (no B field)
2. There is no thermal motion (KT=0)
3. Ions are fixed.
4. Plasma is infinite
5. e^- motion in x direction

We assume in plasma one layer is ions and other layer is electrons. An electron trapped between these layer then it behaves like parallel plate condenser.
Plasma Oscillation is happen due to presence of electric field inside plasma.
When in equilibrium condition $n_i = n_e = n_0$ is



called uniform plasma. If e^- is trapped between imaginary plates
In parallel plate capacitor

$$E = \frac{\sigma}{\epsilon_0} \therefore E = \frac{Q}{\epsilon_0 A}$$

where $d << A$ (2)

$\because \sigma$ = charge/area
where ρ = charge density/volume

$Q = n_e \times Ax$
$= n_e \times Ax$

$$\vec{E} = \frac{n_e A x}{\varepsilon_0 A}$$

$$\therefore \vec{E} = \frac{n_e x}{\varepsilon_0}$$

Force upon electron trapped

$$\vec{F} = -e\vec{E}$$

$$m_e a = -\frac{ne^2 x}{\varepsilon_0}$$

$$a = -\frac{ne^2}{m_e \varepsilon_0} x$$

$$\frac{d^2x}{dt^2} = -\frac{ne^2}{m_e \varepsilon_0} x$$

$$\therefore \boxed{\frac{d^2x}{dt^2} + \left(\frac{n_e^2}{m_e \varepsilon_0}\right) x = 0} \longrightarrow \boxed{1}$$

This is the differential equation

Let us assume

$$x = A \sin \omega t$$

$$\therefore \frac{dx}{dt} = A \omega \cos \omega t$$

$$\therefore \frac{d^2x}{dt^2} = -\omega^2 x$$

$\omega = 2\pi f$

$$\boxed{\frac{d^2x}{dt^2} + \omega^2 x = 0} \quad — \quad ②$$

$$\therefore \frac{d^2x}{dt^2} = -\omega^2 x$$

③ -

From equation [1] & [2]

$$\omega^2 = \frac{n_e e^2}{\varepsilon_0 m_e}$$

$$\boxed{\omega = \omega_{p_e} = \left(\frac{n_e e^2}{m_e \varepsilon_0}\right)^{\frac{1}{2}}}$$ — S.I. unit

This is the angular frequency of electron Plasma.

In C.G.S. unit $\varepsilon_0 = \frac{1}{4\pi}$

$$\Rightarrow \omega_{p_e} = \left(\frac{4\pi n_e e^2}{m_e}\right)^{\frac{1}{2}}$$ C.G.S unit

Example → (1) In laboratory

$n \simeq 10^{15}/m^3$ $f = \frac{1}{2\pi}\left(\frac{n_e e^2}{m_e \varepsilon_0}\right)^{\frac{1}{2}}$

$f_{p_e} \simeq 300$ MHz

(2) In Ionosphere –

$n \simeq 10^{11}/m^3$ $f_{p_e} \simeq 3$ MHz

(3) In sky wave

$f < 3$ MHz

— x —