Langat Singh College, Muzaffarpur
NAAC Grade 'A'
Under B. R. A. Bihar University, Muzaffarpur

Plasma physics –lecture - 05

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This is called the **Debye Length**

- Perturbations to the charge density and potential in a plasma tend to fall off with characteristic length λ_D.

In Fusion plasmas λ_D is typically small. [e.g. $n_e = 10^{20} m^{-3}$ T_e = 1keV $\lambda_D = 2 \times 10^{-5}$m = 20μm]

- Usually we include as part of the definition of a plasma that $\lambda_D <<$ the size of plasma. This ensures that collective effects, quasi-neutrality etc. are important. Otherwise they probably are not.

Plasma-Solid Boundaries (Elementary)

When a plasma is in contact with a solid, the solid acts as a "sink" draining away the plasma. Recombination of electrons and ions occur at surface. Then:

1. Plasma is normally charged positively with respect to the solid.

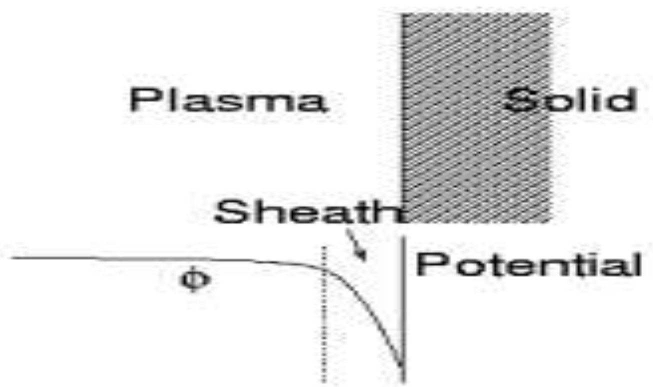

Figure 7: Plasma Solid interface: Sheath

- 2. There is a relatively thin region called the "sheath", at the boundary of the plasma, where the main potential variation occurs.

Reason for potential drop:

- Different velocities of electrons and ions.

If there were no potential variation (E= 0) the electrons and ions would hit the surface at the random rate

$$\frac{1}{4}n\bar{v} \text{ per unit area} \qquad (25)$$

- This equation comes from elementary gas-kinetic theory.

See problems if not familiar.

The mean speed $\bar{\upsilon} = \sqrt{\frac{8T}{\pi m}} \sim \sqrt{\frac{T}{m}}$

- Because of mass difference electrons move $\sqrt{\frac{m_i}{m_e}}$ faster and hence would drain out of plasma m_e faster.
- Hence, plasma charges up enough that an electric field opposes electron escape and reduces total electric current to zero.

Estimate of potential:

Ion escape flux $\frac{1}{4}n_i'\bar{v}_i$

Electron escape flux $\frac{1}{4}n_e'\bar{v}_i$

Prime denotes values at solid surface.

Boltzmann factor applied to electrons: (26)

$$n_e' = n_\infty \exp[e\phi_s/T_e]$$

where ϕ_s is solid potential relative to distant (∞) plasma.

- Since ions are being dragged out by potential assume $n_i^l \sim n_\infty$ ($Z_i = 1$). [This is only approximately correct.]
- Hence total current density out of plasma is

$$j = q_i \frac{1}{4} n_i' \bar{v}_i + q_e \frac{1}{4} n_e' \bar{v}_e \qquad (27)$$

$$= \frac{e n_\infty}{4} \left\{ \bar{v}_i - \exp\left[\frac{e\phi_s}{T_e}\right] \bar{v}_e \right\} \qquad (28)$$

This must be zero so

$$\phi_s = \frac{T_e}{e}\ln\left|\frac{\bar{v}_i}{\bar{v}_e}\right| = \frac{T_e}{e}\frac{1}{2}\ln\left(\frac{T_i}{T_e}\frac{m_e}{m_i}\right) \tag{29}$$

$$= \frac{T_e}{e}\frac{1}{2}\ln\left(\frac{m_e}{m_i}\right) \quad [\text{if } T_e = T_i.] \tag{30}$$

For hydrogen $\frac{m_i}{m_e}$ = 1800 so $\frac{1}{2}$ ln$\frac{m_i}{m_e}$ = −3.75.
The potential of the surface relative to plasma is approximately −4 $\frac{T_e}{e}$ [Note $\frac{T_e}{e}$ is just the electron temp r in electron volts expressed as a voltage.]

Thickness of the sheath

- Crude estimates of sheath thickness can be obtained by assuming that ion density is uniform.
- Then equation of potential is, as before

$$\frac{d^2\phi}{dx^2} = \frac{en_\infty}{\epsilon_0}\left[\exp\left(\frac{e\phi}{T_e}\right) - 1\right] \quad (31)$$

- We know the rough scale length of solutions of this equation is

$$\lambda_D = \left(\frac{\epsilon_0 T_e}{e^2 n_\infty}\right)^{\frac{1}{2}} \quad \text{the Debye Length.} \quad (32)$$

- Actually our previous solution was valid only for $|e\phi/T_e| << 1$ which is no longer valid. When $-e\phi/T_e > 1$ (as will be the case in the sheath).
- We can practically ignore the electron density, in which case the solution will continue only quadratically. One might expect, therefore, that the sheath thickness is roughly given by an electric potential gradient

$$-\frac{T}{e}\frac{1}{\lambda_D}$$

extending sufficient distance to reach $\phi_S = -4\frac{T_e}{e}$ i.e. (33)

distance $x \sim 4\lambda_D$

This is correct for the typical sheath thickness but not at all rigorous.