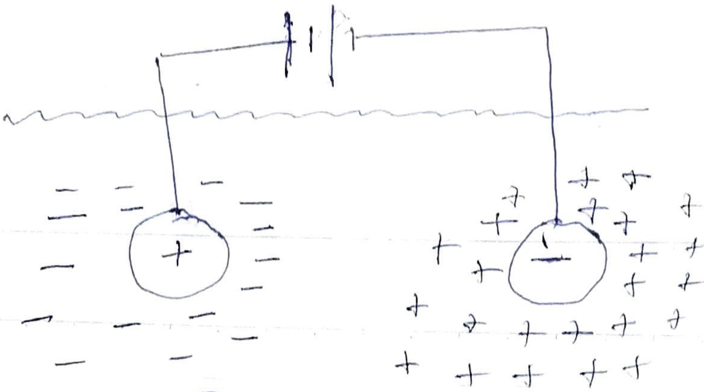


Debye shilding

Two charged balls connected to battery

cloud of ~~ions~~ electrons surround positive ball

cloud of ~~electrons~~ ions surround negative ball

Layer of dieletor keeps the plasma from actually recombining on the surface ~~and~~ or the battery is large enough to maintain potential despite of this.

Cold Plasma :— No thermal motion

↳ as many charges in cloud as in the ball → shielding would be perfect → no electric field present in the body ~~in the body~~ of the plasma outside the clouds

Finite Temperature :— Particles at the edge of the cloud → electric field is weak, have ~~enough~~ thermal energy to escape from the electrostatic potential wall.

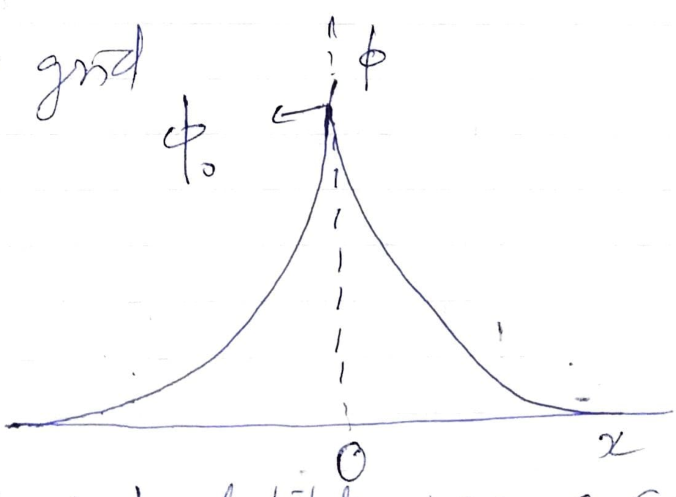
The edge of cloud → at the radius where the potential energy is approximately equal to the thermal energy KT of the particles,

→ shielding is not complete.

Potentials of the order $\frac{KT}{e}$ can leak into the plasma and cause finite electric ~~E~~ fields to exist there

- Approximate thickness of such a charge cloud

Imagine that the potential ϕ on the plane $x = 0$ is held at a value ϕ_0 by a perfectly transparent grid



Potential distribution near a grid in a plasma

Assume ion-electron mass ratio $\frac{M}{m}$ is infinite,

→ ions do not move but form a uniform background of positive charge.

Poisson's eq^n in one dimension is

$$\varepsilon_0 \nabla^2\phi = \varepsilon_0 \frac{d^2\phi}{dx^2} = -e(n_i - n_e)$$

$(z=1)$

——(1)

If the density far away is n_∞, we have $n_i = n_\infty$

In the presence of a potential energy $q\phi$, the electron distribution function is

$$f(u) = A \exp\left[-\left(\tfrac{1}{2}mu^2 + q\phi\right)/kT_e\right]$$

There are fewer particles at places where the potential energy is large

Integrating $f(u)$ over u, setting $q = -e$ and noting that $n_e(\phi \to 0) = n_\infty$

$$n_e = n_\infty \exp(e\phi/kT_e)$$

Substituting for n_i and n_e in eq^n(1)

$$\varepsilon_0 \frac{d^2\phi}{dx^2} = e n_\infty \left\{\left[\exp\left(\frac{e\phi}{kT_e}\right)\right] - 1\right\}$$

In the region where $|e\phi/kT_e| \ll 1$, we can expand the exponential in Taylor Series

$$\varepsilon_0 \frac{d^2\phi}{dx^2} = e n_\infty \left[\frac{e\phi}{kT_e} + \frac{1}{2}\left(\frac{e\phi}{kT_e}\right)^2 + \cdots\right]$$

——(2)

keeping only linear terms

$$\varepsilon_0 \frac{d^2\phi}{dx^2} = \frac{n_\infty e^2}{kT_e}\phi \quad \text{--- (3)}$$

defining $$\lambda_D = \left(\frac{\varepsilon_0 k T_e}{n e^2}\right)^{\frac{1}{2}} \quad \text{--- (4)}$$

n for n_∞, sol^n of eq^n (3)

$$\phi = \phi_0 \exp(-|x|/\lambda_D) \quad \text{--- (5)}$$

λ_D → Debye length → is a measure of the shielding distance or thickness of the sheath.

As density is increased → λ_D decreases
→ each layer of plasma contains more electrons.

λ_D increases → with increasing KT_e.
Without thermal agitation, the charge cloud would collapse to an infinitely thin layer.

From eq^n (4)

$$\lambda_D = 69\left(\frac{T}{n}\right)^{\frac{1}{2}} m \quad T \text{ in } {}^\circ K$$

$$\lambda_D = 7430\left(\frac{KT}{n}\right)^{\frac{1}{2}} m, \quad KT \text{ in } eV$$

Quasineutrality

If the dimensions L of a system are much larger than λ_D → whenever local concentrations of charge arise or external potentials are introduced into the system, these are shielded out in a distance short compared with L, leaving the bulk of plasma free of large electric potentials or fields.

Outside of the sheath on the wall or on an obstacle, $\nabla^2\phi$ is very small, and n_i is equal to n_e. It takes only a small charge imbalance to give rise to potentials of the order of KT/e. The plasma is quasineutral i.e. neutral enough so that one can take $n_i \simeq n_e \simeq n$, where n → common density called the plasma density → not so neutral that all the interesting electro-magnetic forces vanish.

A criterion for an ionized gas to be plasma → dense enough that λ_D is much smaller than L

The Plasma Parameter

Criteria of Debye shielding valid only if there are enough particles in the charge cloud. If there are only one or two particles in the sheath region ⟶ Debye shielding not a valid concept.

No. of particles in a Debye sphere

$$N_D = n \frac{4}{3}\pi \lambda_D^3$$

$$= 1.38 \times 10^6 \, T^{3/2} / n^{1/2} \quad (T \text{ in } {}^\circ K)$$

in addition to $\lambda_D << L$

"Collective behaviour" requires

$$N_D >>> 1$$

Criteria for Plasma

We have given two conditions that an ionized gas must satisfy to be called plasma

Third condition ⟶ regarding collisions

Weakly ionized gas in jet exhaust ⟶ not qualify for plasma because the charged particles collide so frequently with neutral atoms that their motion is controlled by ordinary hydrodynamic forces ⟶ not by electromagnetic forces.