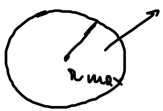
How large is the volume where charge neutrality can be violated in a plasma?



sphere is depleted of electrons

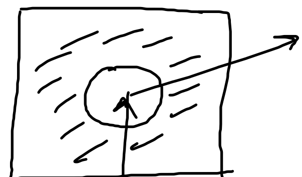
r_{max} is the maximum radius of a sphere which violates charge neutrality

Initially

Electron kinetic energy

electrons/ions in motion

at the end



ions in motion.
No electrons (at rest on the surface at $r=r_{max}$)

electrostatic energy due to unscreened ions

Electron kinetic energy: T_e $\qquad n_e \longrightarrow$ electr. density

$\nearrow$ electr. temp.

In sphere with $r = r_{max}$ $\qquad$ # electrons $= \frac{4}{3}\pi r_{max}^3 \cdot n$

Total Energy (kinetic) $=$ # electrons $\times$ $\underbrace{\text{average kinetic en / electron}}_{\frac{3}{2}T_e}$

$$= \frac{\cancel{4}^{\,2}}{\cancel{3}}\pi r_{max}^3 \cdot n \cdot \frac{\cancel{3}}{\cancel{2}_{\,1}} T_e$$

equipartition theorem: $\overset{T}{U} = \frac{3}{2}T$

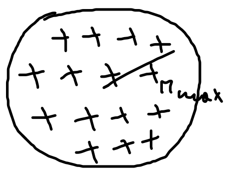
Electrostatic energy due to the unscreened ions

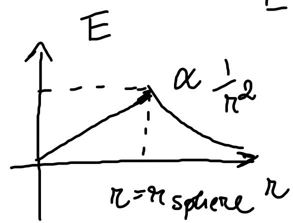
$$W_E = \int_{\text{sphere}} w_E \cdot dV = \int_{\text{sphere}} \frac{1}{2}\varepsilon_0 E^2 \, dV$$

w_E ↗ electrostatic energy density $= \frac{1}{2}\varepsilon_0 E^2$

$E = ?$

E from a uniformly charged sphere





$$E = \frac{\rho}{3\varepsilon_0} \cdot r$$

$\rho \rightarrow$ charge density

$$= \frac{n \cdot e}{3\varepsilon_0} \cdot r$$

$$U_E = \int_{sphere} \frac{1}{2}\varepsilon_0 \left(\frac{ne}{3\varepsilon_0} r\right)^2 4\pi r^2 \, dr =$$

$$= \frac{1}{\cancel{2}_{1}}\cancel{\varepsilon_0} \int_0^{r_{max}} \frac{n^2 e^2}{9\varepsilon_0^{\cancel{2}}} r^2 \, \overset{2}{\cancel{4}}\pi r^2 \, dr =$$

$$= \frac{n^2 e^2 \, 2\pi}{9\varepsilon_0} \int_0^{r_{max}} r^4 \, dr = \frac{2n^2 e^2 \pi}{9\varepsilon_0} \frac{1}{5} r_{max}^5$$

$$= \frac{2n^2 e^2 \pi}{45\varepsilon_0} r_{max}^5$$

$$U_E = K_{electrons} \; ; \; \overbrace{\cancel{2\pi r^3_{max}} \, \cancel{n} T_e}^{K_{electrons}} = \frac{\cancel{2}\cancel{n^2} e^2 \cancel{\pi}}{45\varepsilon_0} \overset{2}{\cancel{r^5_{max}}}$$

$$r_{max}^2 = 45 \, \frac{\varepsilon_0 T_e}{ne^2} \rightarrow \lambda_{De}^2$$

$r_{max} \approx 7\,\lambda_{De}$

$\lambda_{De} \approx$ few to some μm

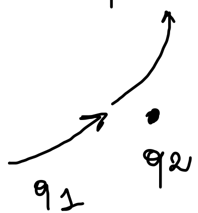
cold plasma

fully ionized plasma

Plasma is quasi neutral

Potential of each individual charge that makes up the plasma is screened within a few λ_D

Coulomb force



If $dist(q_1, q_2) \gg \lambda_D$: q_1 and q_2 do <u>not</u> influence each other (Debye screening)

If $dist(q_1, q_2) < \lambda_D$, $\approx \lambda_D$: q_1 and q_2 will deflect each other $\rightarrow$ collision