$\nu = \sigma^* n v$ Small angle collisions

↗ collisional frequency

$\sigma^* = \frac{q_1^2 q_2^2}{2\pi\varepsilon_0^2 \mu^2 v_{rel}^4} \ln\Lambda$

. Momentum exchange: Fast particle → (plasma)

How long it takes for the fast particle to transf. a significant fraction of it mom. to the bulk plasma

Energy exchange: fast particle to transf. a significant fraction of energy to bulk

Two types of particle: e, i

4 types of collisions

e-e e-i

i-e i-i

[Momentum ν_{ei} ν_{ee} ν_{ie} ν_{ii}

Energy ν_{Eei} ν_{Eee} ν_{Eie} ν_{Eii}

ν_{ei}

$n \sim n_e = n_i$

$\nu = n \sigma^* v_{rel}$

$v_{rel} \longrightarrow \simeq v_{the}$

$\sigma^* \propto \frac{1}{\mu^2} \frac{1}{v_{the}^4}$

$m_e \ll m_i$

$T_e \sim T_i \Rightarrow v_{the} \gg v_{thi}$

$\frac{\nu_{ee}}{\nu_{ei}} \simeq \frac{n_e}{n_e} \frac{\sigma^*_{ee}}{\sigma^*_{ei}} \frac{v_{the}}{v_{the}} \propto \frac{\mu^2_{ei}}{\mu^2_{ee}}$

$$\mu_{ei} = \frac{m_e m_i}{m_i + m_e} \underset{m_i \gg m_e}{\approx} \frac{m_e m_i}{m_i} \approx m_e$$

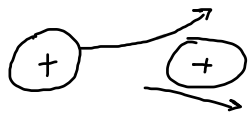
$$\mu_{ee} = \frac{m_e m_e}{m_e + m_e} = \frac{m_e}{2} \qquad \mu_{ei} = O(\mu_{ee})$$

$$\nu_{ei} = O(\nu_{ee})$$

$$\nu_{ii} = n_i \cdot \sigma^*_{ii} \, v_{Ti} \propto n_i \frac{1}{\mu_{ii}^2 v_{Ti}^4} \cdot v_{Ti} \propto n_i \frac{1}{m_i^2} \frac{1}{v_{Ti}^3} \propto n_i \frac{1}{m_i^2} \cdot \frac{m_i^{3/2}}{T^{3/2}}$$

$$\nu_{ei} = n_e \sigma^*_{ei} v_{Te} \propto \frac{n_e}{m_e^{1/2}} \cdot \frac{1}{T^{3/2}} \propto \frac{n_i}{m_i^{1/2}} \cdot \frac{1}{T^{3/2}}$$

$$\frac{\nu_{ii}}{\nu_{ei}} \approx \left(\frac{m_e}{m_i}\right)^{\frac{1}{2}} \approx \frac{1}{40}$$

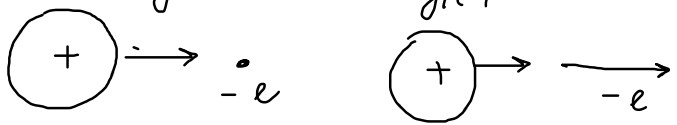


$\nu_{ie} = ?$

$\nu_{ie} \ll \nu_{ei}$

Cons. momentum:

$$m_i \Delta \underline{v}_i = -m_e \Delta \underline{v}_e \; ; \quad \Delta \underline{v}_i = -\frac{m_e}{m_i} \Delta \underline{v}_e$$



$\underline{v}_e = 2\underline{v}_i$

$\Delta \underline{v}_e \approx \underline{v}_i$

$\Delta \underline{v}_i \approx \frac{m_e}{m_i} \cdot \underline{v}_i$

$\frac{\Delta v_i}{v_i} \approx \frac{m_e}{m_i}$

$\frac{\Delta v_i}{v_i} \approx 1$

It takes $\frac{m_i}{m_e}$ more collisions

significant change of momentum

$\nu_{ie} \sim \frac{m_e}{m_i} \nu_{ei}$

ν_{ei}

$O(1)$ $\quad O\left(\left(\frac{m_e}{m_i}\right)^{\frac{1}{2}}\right)$ $\quad O\left(\frac{m_e}{m_i}\right)$

ν_{ei} $\quad \nu_{ii}$ $\quad \nu_{ie}$

ν_{ee}

ν_E