Large angle collision: $\theta > \pi/2$ $\quad \sigma_{\theta > \pi/2} = \pi b_{\pi/2}^2$

small " " : $\theta < \pi/2$

$$\sigma^* = 8 \ln\Lambda \, \sigma_{\pi/2}$$

$$\frac{\nu_{small}}{\nu_{large}} = 8 \cdot \ln\Lambda \qquad \ln\Lambda = \ln\left(\frac{\lambda_D}{b_{\pi/2}}\right) \qquad m_i \simeq 2000 m_e$$

$$\lambda_D \simeq \left(\frac{\varepsilon_0 T_e}{n e^2}\right)^{\frac{1}{2}} \qquad b_{\frac{\pi}{2}} = \frac{q_1 q_2}{4\pi \varepsilon_0 \mu v_{rel}^2}$$

$v_{rel} \sim v_{th,e}$ $\quad$ - e $\quad$ i $\quad$ $T_e \sim T_i$ $\quad v_e \sim v_{the} \sim \left(\frac{T_e}{m_e}\right)^{\frac{1}{2}}$

$$\underline{v}_{rel} = \underline{v}_e - \underline{v}_i$$

$$v_i \sim v_{thi} \sim \left(\frac{T_i}{m_i}\right)^{\frac{1}{2}}$$

$$\frac{\lambda_D}{b_{\pi/2}} \approx \left(\frac{\varepsilon_0 T_e}{n e^2}\right)^{\frac{1}{2}} \cdot \frac{4\pi\varepsilon_0 \mu v^2_{th e}}{e^2}, \qquad \mu \approx m_e$$

$$\mu = \frac{m_e m_i}{m_i + m_e} \approx \frac{m_e \cancel{m_i}}{\cancel{m_i}} \approx m_e$$

$m_i >> m_e$

$$b_{\pi/2} \approx \frac{e^2}{4\pi\varepsilon_0 m_e v^2_{th e}} = \frac{e^2}{4\pi\varepsilon_0 \underbrace{m_e \frac{1}{2} v^2_{th e}}_{T_e} \cdot 2} = \frac{n_e e^2}{4\pi n_e \varepsilon_0 T_e \cdot 2} = \frac{1}{\lambda_D^2 \cdot 8\pi n_e}$$

$$\frac{\lambda_D}{b_{\pi/2}} \approx \frac{1}{8\pi n_e \lambda_D}$$

$\lambda_D >> b_{\pi/2}$ $\qquad$ $\ln\Lambda >> 1$

$$\lambda_D >> b_{\pi/2} \qquad \lambda_D >> \frac{1}{\lambda_D^2 8\pi n_e} \Rightarrow n_e \lambda_D^3 >> 1$$

Enough particles in a Debye sphere

$\ln\Lambda \approx 10-20$

$$\sigma^* \simeq 8\ln\Lambda\, \sigma_{\frac{\pi}{2}} \approx 100 \div 200\ \sigma_{\frac{\pi}{2}}$$

Small angle collisions are the most dominant

Small angle coll $\theta < \pi/2$ Large angle coll. $\theta > \pi/2$

$\frac{\pi}{3}$? $\frac{\pi}{4}$? $\frac{2}{3}\pi$?

$$\ln\tilde{\Lambda} = \ln\left(\frac{\lambda_D}{b_{\frac{\pi}{3}, \frac{\pi}{4}, \frac{2}{3}\pi}}\right)$$

Resistivity -

$\underline{E}$ ~~Static~~ $\rightarrow$ inductive

$\underline{F} = q\underline{E}$

$$\left.\begin{aligned} \underline{F}_{el} &= -e\underline{E} \\ \underline{F}_{ion} &= e\underline{E} \end{aligned}\right\} \text{Current}$$

$$\underline{E} = \eta \cdot \underline{j}$$

η : resistivity $\qquad \sigma = \eta^{-1}$

current density $\qquad \underline{j} = \underline{E} / \eta = \sigma \cdot \underline{E}$

Single particle picture

$$m \frac{d\underline{v}}{dt} = q\underline{E} - m\nu \underline{v}$$

Steady state

$$d\underline{v}/dt \approx 0$$

$$\underline{v} = \frac{q\underline{E}}{m \cdot \nu}$$

$$\underline{j} = n \cdot q \underline{v} = \underbrace{\frac{n q^2}{m \cdot \nu}}_{\sigma} \cdot \underline{E}$$

$$\eta = \frac{m\nu}{n q^2}$$

$$\nu = \Gamma \cdot \sigma$$

$$= n \cdot v_{rel} \cdot \sigma$$

$$\nu^* \approx n v_{th} \cdot \sigma^*$$

$$\propto n v_{th} \cdot \sigma_{\pi/2}$$

$$\eta = \frac{m\nu^*}{ne^2}$$

$$\nu^* \propto n \cdot v_{th} \cdot \sigma_{\pi/2} \propto n v_{th} b^2_{\frac{\pi}{2}}$$

$$\propto n \cdot v_{th} \cdot \frac{1}{v^4_{th}} \propto \frac{1}{v^3_{th}}$$

$$\eta \propto \frac{1}{v^3_{th}} \propto \frac{1}{Te^{3/2}}$$

$$v_{th} \propto T^{\frac{1}{2}}$$

Hotter plasma is less collisional

electron
ion

Hydrogen

e
protons

$\begin{cases} e - i \\ e - e \end{cases}$

$\begin{cases} i - e \\ i - i \end{cases}$

4 types of collisions

ν_{ee} ν_{ie} ν_{ii} ν_{ei}

ν_{Eee} ν_{Eie} ν_{Eii} ν_{Eei}