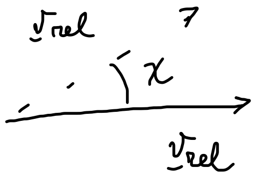
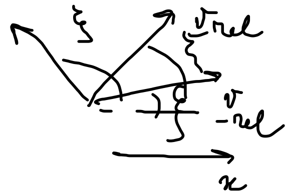
$$\Delta \underline{r}_{gcm} = -\frac{1}{\omega_{cr}}\left[(\underline{v}_{rel} \times \hat{\underline{n}})(\cos\chi - 1) + \underline{v}_{rel}\sin\chi\right]$$

e - i

$$\omega_{cr} = \frac{qB}{\mu} \qquad \mu = \frac{m_i m_e}{m_i + m_e} \qquad \underline{v}_{rel} = \underline{v}_i - \underline{v}_e$$





$$\langle \underline{v}_{rel} \rangle = 0 \qquad \langle \Delta \underline{r}_{gcm} \rangle = 0$$

$$\langle x \rangle = 0$$
$$\langle x^2 \rangle \neq 0$$

$$\langle \Delta r^2_{gcm} \rangle = \left\langle \frac{v^2_{rel}}{\omega^2_{cr}}\left[(1-\cos\chi)^2 + \sin^2\chi\right]\right\rangle = \left\langle \frac{v^2_{rel}}{\omega^2_{cr}}(1 + 1 - 2\cos\chi)\right\rangle = \left\langle \frac{2v^2_{rel}}{\omega^2_{cr}}(1-\cos\chi)\right\rangle$$

$$\langle \Delta r^2_{\text{scm}} \rangle = \frac{\displaystyle\int_0^{2\pi} d\chi \int_0^{2\pi} d\xi \, \frac{2 v_{rel}^2}{\omega_{cr}^2} (1 - \cos\chi)}{\displaystyle\int_0^{2\pi} d\chi \int_0^{2\pi} d\xi} = \frac{\frac{2 v_{rel}^2}{\omega_{cr}^2} \cdot \cancel{4\pi^2}}{\cancel{4\pi^2}}$$

$$= \frac{2 v_{rel}^2}{\omega_{cr}^2}$$

$$v_{rel} = |\underline{v}_i - \underline{v}_e| \simeq v_e \qquad \langle \Delta r^2_{\text{scm}} \rangle \simeq \frac{2 v_{the}^2}{\omega_{ce}^2} \simeq r_{Le}^2$$

$$\mu = \frac{m_i m_e}{m_i + m_e} \underset{m_i \gg m_e}{\simeq} m_e$$

$$\frac{v_{the}}{\omega_{ce}} = \frac{m_e v_{the}}{qB} \sim r_{Le}$$

$$D \sim r_L^2 \cdot \nu \sim r_{Le}^2 \cdot \nu_{ei} \neq r_{Li}^2 \cdot \nu_{ii}$$

$$\frac{D_{correct}}{D_{wrong}} \sim \frac{r_{Le}^2 \nu_{ei}}{r_{Li}^2 \nu_{ii}} \sim \frac{m_e^{\cancel{2}} \cancel{T} \cancel{m_e}}{m_i^{\cancel{2}} \cancel{T} \cancel{m_i}} \sqrt{\frac{m_i}{m_e}}$$

$$\sim \frac{m_e}{m_i} \sqrt{\frac{m_i}{m_e}} \sim \sqrt{\frac{m_e}{m_i}}$$

$$D \sim \frac{m^2 v^2}{q^2 B^2} \cdot \frac{n}{T^{3/2}} \sim \frac{T}{B^2} \frac{n}{T^{3/2}} \sim \frac{n}{B^2 T^{\frac{1}{2}}} \quad [m^2/s]$$

Braginskii diffusion coefficient

$$D = 2\cdot 10^{-3}\ \frac{n_{20}}{B^2\, T_k^{-\frac{1}{2}}}\quad [m^2/s]$$

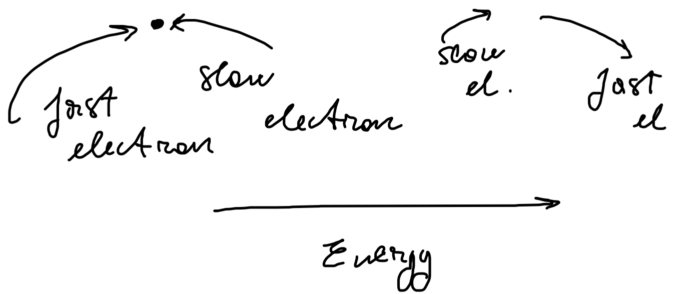
$n_{20} = \frac{n}{10^{20}\, m^{-3}}$ B in Tesla T_k : temperature in keV

eg JET $T = 5$ keV $n_{20} = 0.5$ $B_0 = 3$ T

Prediction: $D \approx 5\cdot 10^{-5}\ m^2/s$

Experiment: $D \sim m^2/s$

Transport of energy —



$$\Delta \underline{r}_{CE} = \underline{r}'_{CE} - \underline{r}_{CE}$$

$$\underline{r}_{CE} = \frac{v_1^2 \underline{r}_{g1} + v_2^2 \underline{r}_{g2}}{v_1^2 + v_2^2} \qquad \underline{r}'_{CE} = \frac{v_1'^2 \underline{r}'_{g1} + v_2'^2 \underline{r}'_{g2}}{v_1'^2 + v_2'^2}$$

$$(\Delta l)^2 = \frac{2 v_{rel}^4 V_{cm}^2}{\omega_c^2 \left(4 V_{cm}^2 + v_{rel}^2\right)^2}$$

$$v^2_{rel} = (\underline{v}_1 - \underline{v}_2)^2 = v_1^2 + v_2^2 - 2\,\underline{v}_1\cdot\underline{v}_2$$

$$\langle v^2_{rel}\rangle \sim 2 v^2_{th} \qquad \langle \underline{v}_1\cdot\underline{v}_2\rangle = 0$$

$$V^2_{cm} = \frac{1}{4}(\underline{v}_1+\underline{v}_2)^2 = \frac{1}{4}(v_1^2+v_2^2+2\,\underline{v}_1\cdot\underline{v}_2)$$

$$\langle V^2_{cm}\rangle \sim \frac{v^2_{th}}{2}$$

$$(\Delta l)^2 \sim \frac{v^6_{th}}{v^4_{th}\,\omega_c^2} \sim \frac{v^2_{th}}{\omega_c^2} \sim r_L^2$$

<u>diffusivity</u>

i i $\qquad \chi_{ii} \sim r^2_{Li}\,\nu_{ii}$

e e $\qquad \chi_{ee} \sim r^2_{Le}\,\nu_{ee}$

$$\chi \propto \frac{n}{B^2 T^{\frac{1}{2}}}$$

$$\frac{\chi_{ii}}{\chi_{ee}} \sim \frac{r_{Li}^2}{r_{Le}^2}\frac{\nu_{ii}}{\nu_{ee}} \sim \frac{m_i^2 v_{thi}^2}{m_e^2 v_{the}^2}\cdot\left(\frac{m_e}{m_i}\right)^{\frac{1}{2}}$$

$$\sim \frac{\cancel{m_i^2}\,\cancel{T}/\cancel{m_i}}{m_e^2\,\cancel{T}/\cancel{m_e}}\frac{\nu_{ii}}{\nu_{ee}} \sim \frac{m_i}{m_e}\left(\frac{m_e}{m_i}\right)^{\frac{1}{2}} \sim \left(\frac{m_i}{m_e}\right)^{\frac{1}{2}} \sim 40$$

$$\chi_i \simeq 0.10\,\frac{n_{20}}{B_0^2 T^{\frac{1}{2}}}\ m^2/s \qquad \chi_e = 4.8\cdot 10^{-3}\,\frac{n_{20}}{B_0^2 T^{\frac{1}{2}}}\ m^2/s$$

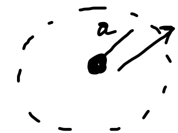
e.g. JET $T \simeq 5$ keV $B_0 \simeq 3$ T

$n_{20} \simeq 0.5$

$\chi_i \simeq 2.5\cdot 10^{-3}\ m^2/s \qquad \chi_{exp} \sim m^2/s$

Diffusion equation

$$\frac{\partial n}{\partial t} + \underline{\nabla}\cdot\underline{\Gamma} = 0 \quad \text{and} \quad \underline{\Gamma} = -D\underline{\nabla} n$$



$$\frac{\partial n}{\partial t} \sim \frac{n}{\tau} \qquad \underline{\nabla}\cdot\underline{\Gamma} = -D\nabla^2 n \sim \frac{Dn}{a^2}$$

$$\frac{\cancel{n}}{\tau} - \frac{D\cancel{n}}{a^2} \approx 0 \; ; \; \tau \approx a^2/D$$

$$\tau_E \approx a^2/\chi$$

α particles

3.5 MeV $\longrightarrow$ thermal vel.

ESL $< \tau_{\text{part.}}$