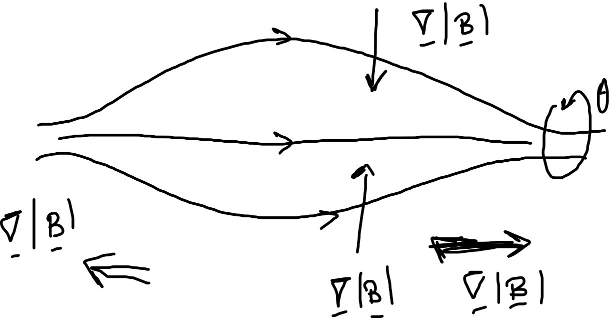


Confined particles

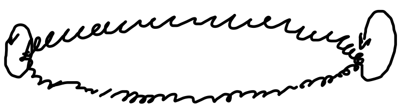
$$\int v_\parallel \, ds$$

$\nabla |B| \propto \hat{e}_r$

Curvature $\propto \hat{e}_r$

$$\underline{v}_D = -\mu \frac{\nabla |\underline{B}| \times \underline{B}}{qB^2} \propto \hat{\underline{e}}_\theta$$

$$\underline{v}_{centr} = -\frac{(\hat{\underline{b}} \cdot \underline{\nabla})\hat{\underline{b}}\, m v_\parallel^2 \times \underline{B}}{qB^2} \propto \hat{\underline{e}}_\theta$$



New periodic motion: that of the T.P.

$$\langle \underline{v} \rangle = \frac{1}{\tau_{bounce}} \int_0^{t_b} \underline{v}\, dt \qquad J_3 = \int \left(m\langle \underline{v}\rangle + q\,\underline{A}\right)\cdot d\underline{r}_{bounce}$$

$$\frac{\int m\langle \underline{v}\rangle \cdot d\underline{r}_{bounce}}{\int q\,\underline{A}\cdot d\underline{r}_{bounce}}$$

TP

$$\underline{B} = \nabla \times \underline{A}$$

Stokes th.

$$\int \underline{B}\cdot d\underline{S} = \int (\nabla\times\underline{A})\cdot d\underline{S} = \oint \underline{A}\cdot d\underline{l}$$

$$\frac{\frac{m^2}{\cancel{q}Br}\left(\frac{v_\perp^2}{2} + v_\parallel^2\right)\cdot r}{q\,\Phi(\underline{B})_{\text{orbit of T.P.}}} \overset{v_\parallel \sim v_\perp}{\approx} \frac{\frac{m^2}{qB\cancel{r}}\,v^2\cdot\cancel{r}}{qB\pi r^2}$$

$$\langle \underline{v} \rangle = \underline{v}_{\nabla|B|} + \underline{v}_{centr}$$

$$\underline{v}_{\nabla|B|} = -\mu\,\frac{\nabla|\underline{B}|\times\underline{B}}{qB^2} \qquad \underline{v}_{centr} \approx -\frac{mv_\parallel^2}{r}\,\frac{\hat{\underline{r}}\times\hat{\underline{B}}}{qB^2}$$

$$|\underline{v}_{centr}| \approx \frac{mv_\parallel^2}{r}\,\frac{\cancel{B}}{qB^{\cancel{2}}} \approx \frac{mv_\parallel^2}{qBr}$$

$$|\underline{v}_{\nabla|B|}| \approx \frac{mv_\perp^2}{2B}\,\frac{\cancel{B}}{r}\cdot\frac{B}{qB^{\cancel{2}}} \approx \frac{mv_\perp^2}{2qBr}$$

$$\frac{\int m\langle \underline{v}\rangle\cdot d\underline{r}_{bounce}}{\int q\,\underline{A}\cdot d\underline{r}_{bounce}} \approx \frac{\left(\frac{mv}{qB}\right)^2}{\pi r^2} \approx \left(\frac{r_L}{r}\right)^2 \ll 1$$

size of T.P. orbit

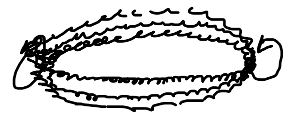
$$J_3 = \int (m\langle \underline{v}\rangle + q\,\underline{A})\,d\underline{r}_{bounce} \approx \int q\,\underline{A}\cdot d\underline{r}_{bounce} = q\,\Phi(\underline{B})_{T.P.\ orbit}$$

μ : τ_L

J_2 : τ_b

J_3 : $\tau_{Precession}$

$\cancel{\tau_L} \ll \cancel{\tau_b} \ll \cancel{\tau_{Precession}}$



Waves

$\omega_L = \frac{qB}{m}$ $\quad T_L = \frac{2\pi}{\omega_L} = \frac{2\pi m}{qB}$

$m = m_p = 1.67\cdot 10^{-27}\,kg$

$B = 1\,T$ $\quad T_L \approx \frac{6\cdot 10^{-27}\cdot 1.67}{1.6\cdot 10^{-19}} \approx 10^{-7}\,s \approx 0.1\,\mu s$

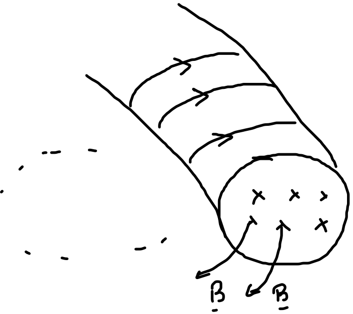
Electrons

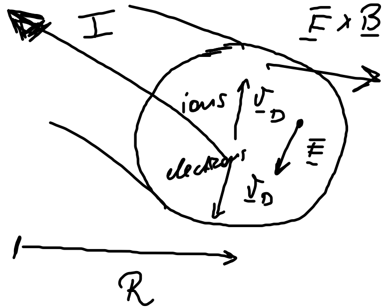
$T_L \propto m \qquad \frac{m_e}{m_p} \approx \frac{1}{2000} \qquad T_{L,e} \approx 0{,}1 \ \mu s$

$T_{bounce} \sim \frac{\text{size system}}{\text{thermal speed}} \sim \frac{\text{few m}}{10^6 \ m/s} \approx \text{few } \mu s$

$\left.\begin{array}{l} T \sim keV \\ m = m_p \end{array}\right\} v_{th} \approx 10^6 \ m/s$

$T_{precession} \sim \text{few } T_{bounce} \sim \text{some tens of } \mu s$



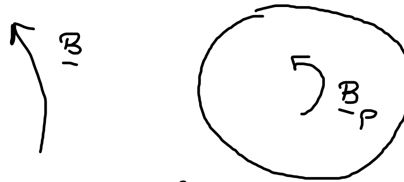


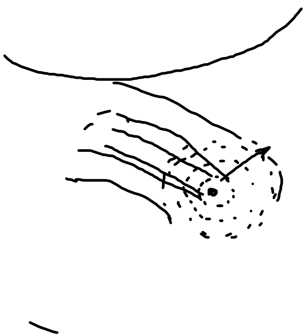
$$B = \frac{B_0 R_0}{R}$$

$$\underline{v}_D = \frac{\underline{E} \times \underline{B}}{B^2} \qquad B = \frac{k}{R}$$

Al centro $k = B_0 R_0$

$$\Rightarrow B = \frac{B_0 R_0}{R}$$





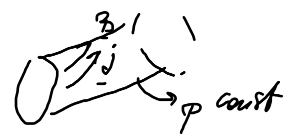
Ideal MHD eq. for eq.

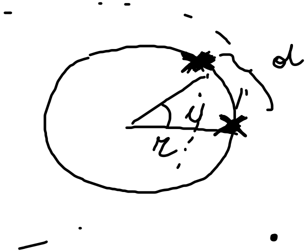
Equilibrium : $\nabla p = \underline{j} \times \underline{B}$

pressure

current density

$\underline{j} \parallel \underline{B} \parallel p$ const



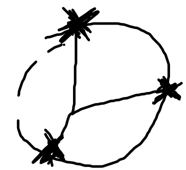


$$\iota = \frac{d}{r}$$

Rotational transform

$\frac{\iota}{2\pi}$ is a rational number

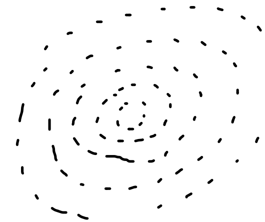
$\frac{\iota}{2\pi}$ = not = = =

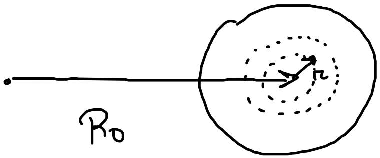


eg. $\frac{\iota}{2\pi} = \frac{1}{3}$

$\frac{2}{3}$

Poincaré plot

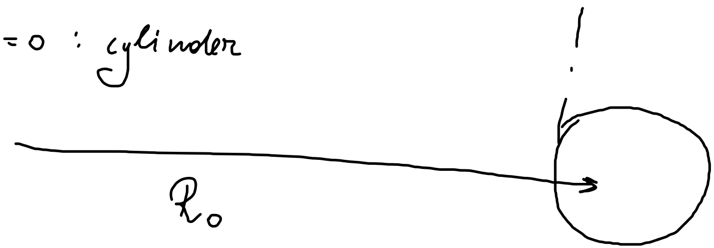




$\frac{r}{R_0} = \varepsilon$ $\frac{R_0}{r}$ = aspect ratio

Typically $\frac{R_0}{r} \gg 1$; $\varepsilon \ll 1$

When $\varepsilon = 0$: cylinder

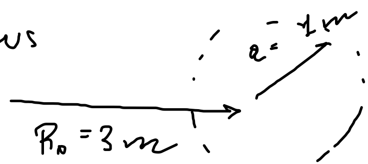


$R_0 \to +\infty$ cylinder

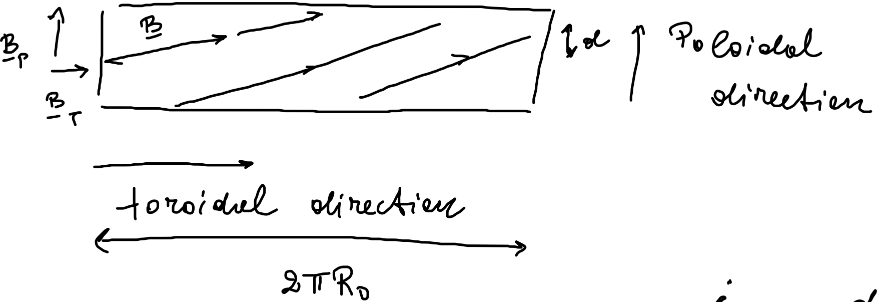
$\frac{r}{R_0} \to 0$

$\varepsilon \ll 1$: cylindrical approx

Joint European Torus



$\varepsilon_{\text{most outer surface}} = \frac{1}{3}$



$$\frac{B_p}{B_T} = \frac{d}{2\pi R_0} \Rightarrow d = 2\pi R_0 \frac{B_p}{B_T}$$

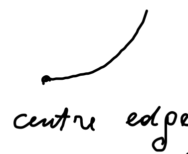
$$\iota = \frac{d}{r} = \frac{2\pi R_0 B_p}{r B_T}$$

Safety factor

$$q = \frac{2\pi}{\iota} = \frac{r B_T}{R_0 B_p}$$

Stability considerations

$1 \lesssim q <$ some units
3,4



$$\frac{B_T}{B_p} = \frac{R_0}{r} \cdot q \gg 1$$

$$\Rightarrow B_T \gg B_p$$

$B_T \sim$ some T

$B_p \sim$ fraction of T