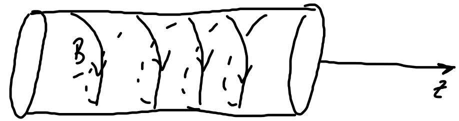
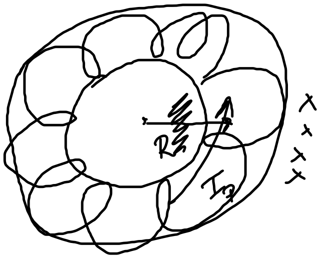
$\nabla p = j \times B$



$\beta \le 1$



Tokamak

Campo toroidale $\propto \frac{1}{R}$

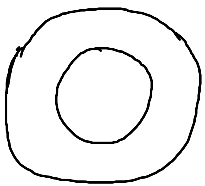
Campo poloidale

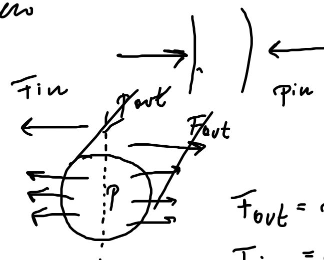
più intenso all'interno del toro

meno intenso all'esterno

$p_m = \frac{B^2}{2\mu_0}$

Tyre tube force





Hoop force

F_{out}

$F_{out} = p S_{out}$

$F_{in} = p S_{in}$

Nel cilindro: $S_{in} = S_{out}$

$F_{out} = F_{in}$

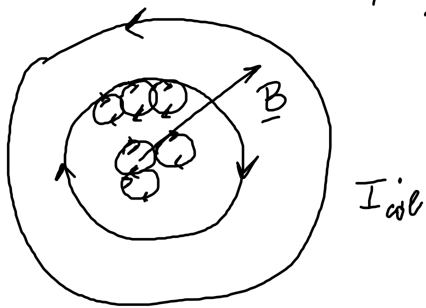
Nel toro: $S_{out} > S_{in}$

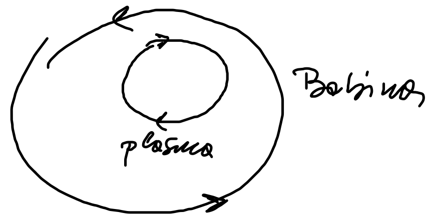
$F_{out} > F_{in}$

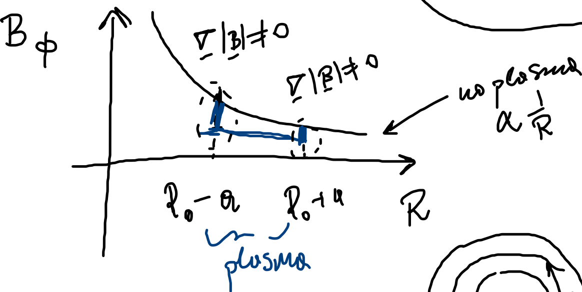
Forza $\frac{1}{R}$

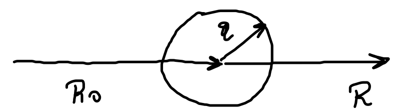
In molti casi il plasma è diamagnetico

$B_{pl} < B_{vuoto}$





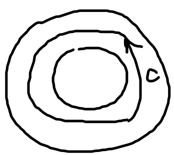




Th ampere

$$\oint \underline{B} \cdot d\underline{l} = \mu_0 I_{coil} - \mu_0 I_{pl}$$

$I_{pl} << I_{coil}$

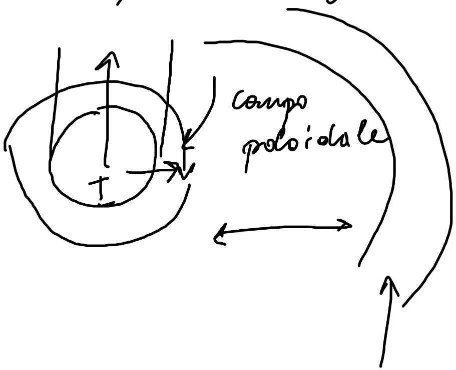


$$2\pi R B = \mu_0 I_{coil} - \mu_0 I_{pl}$$

$$B \approx \frac{\mu_0}{2\pi R} (I_{coil} - I_{pl})$$

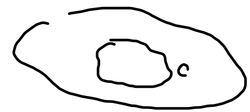
∃ un gradiente di $p_m = B^2/2\mu_0$ sulla sup. interna ed est

$S_{ext} > S_{int}$; c'è una forza che spinge vs esterno



Se il plasma va vs esterno, le linee di campo poloidale esterne si schiacciano $\Rightarrow$ $p_m \uparrow$

? conduttore reale ?



Legge di Galo: $\Phi = \text{const}$

$$\frac{d\Phi}{dt} = \int_S \frac{\partial \underline{B}}{\partial t} \cdot d\underline{S} + \int_C \underline{B}(t) \cdot (\underline{u}_\perp \times d\underline{\ell})$$

$$\underline{E} + \underline{u}_\perp \times \underline{B} = \eta \underline{j} \quad \text{MHD resistiva}$$

$$\partial \underline{B} / \partial t = -\underline{\nabla} \times \underline{E} = -\underline{\nabla} \times (\eta \underline{j} - \underline{u}_\perp \times \underline{B})$$

$$\frac{d\phi}{dt} = \int_S \underline{\nabla} \times (-\eta \underline{j} + \underline{u}_\perp \times \underline{B}) \cdot d\underline{S} + \int_C \underline{B}(t) \cdot (\underline{u}_\perp \times d\underline{l})$$

$$= -\int_S \underline{\nabla} \times (\eta \underline{j}) \cdot d\underline{S} \cancel{\int_C (\underline{u}_\perp \times \underline{B}) \cdot d\underline{l} + \int_C \underline{B} \cdot (\underline{u}_\perp \times d\underline{l})}$$

$\neq 0$

legge di Faraday $\quad \frac{\partial \underline{B}}{\partial t} = -\underline{\nabla} \times \underline{E} = \underline{\nabla} \times (\underline{u}_\perp \times \underline{B}) - \underline{\nabla} \times (\eta \underline{j})$

Th. Ampere $\quad \frac{\underline{\nabla} \times \underline{B}}{\mu_0} = \underline{j}$

$$\frac{\partial \underline{B}}{\partial t} = \underline{\nabla} \times (\underline{u}_\perp \times \underline{B}) - \frac{\eta}{\mu_0} \underbrace{\underline{\nabla} \times (\underline{\nabla} \times \underline{B})}_{\underline{\nabla}(\cancel{\underline{\nabla} \cdot \underline{B}}) - \nabla^2 \underline{B}}$$

$\eta = \text{const}$

$\underline{\nabla} \cdot \underline{B} = 0$

$$\frac{\partial \underline{B}}{\partial t} = \underline{\nabla} \times (\underline{u}_\perp \times \underline{B}) + \frac{\eta}{\mu_0} \nabla^2 \underline{B}$$

Se $\eta = 0$ $\quad \partial \underline{B}/\partial t = \underline{\nabla} \times (\underline{u}_\perp \times \underline{B})$ $\quad$ legge di gelo

Trascuro la legge di gelo

$\partial \underline{B}/\partial t = \frac{\eta}{\mu_0} \nabla^2 \underline{B}$ $\quad$ Eq. diffusione

$$\frac{\partial B}{\partial t} = \frac{\eta}{\mu_0}\nabla^2 \underline{B}$$

$$\frac{B}{\tau} \approx \frac{\eta}{\mu_0}\frac{B}{L^2}$$

τ : temposcala

L : dim. sistema

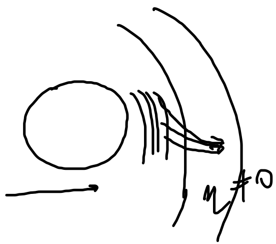
$$\tau \approx \frac{\mu_0}{\eta} L^2 \qquad \tau \propto \frac{1}{\eta}$$

Se $\eta \to 0$ $\tau \to +\infty$

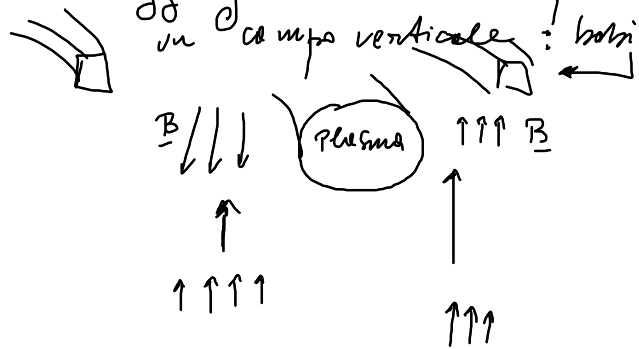
$L \approx 1\ m$

$\eta_{Rame} \approx 1.7 \cdot 10^{-8}\ \Omega \cdot m$

$$\tau \approx \frac{4\pi \cdot 10^{-7}}{1.7 \cdot 10^{-8}} \approx 74\ s \qquad \tau_{RAD} \sim \frac{L}{v_{th}} \sim \mu s$$



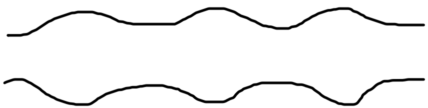
Aggiungere bobine che producono un campo verticale : bobine poloidali



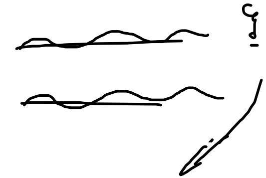
Configurazioni equilibrio: stabili per MHD ideale

se instabili = = reale → sviluppo di sistemi di controllo

$$W = (\text{energia dei campi}) + (\text{energia cinetica})$$

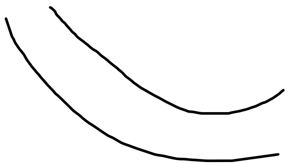


Sausage instability



$\delta W < 0$

$W_{pert} < W_{eq}$



Kink instability