$\nu_{ii} < \omega_B < \nu_{ie}$ $\quad \bar{T}_B \sim 100\ keV$ $\quad E_{fusion} \sim MeV$

$T \sim keV$ $\quad x = \dfrac{\omega}{\nu_{ii}}$ | products

$T_i \sim T_e \Rightarrow \nu_{ie} >> \nu_{ii}$

$$\frac{d\omega}{dt} = \frac{e^2 q_T^2 \ln\Lambda n_e}{4\pi\varepsilon_0^2 m_T^2}\left[\left(1+\frac{m_T}{m_e}\right)\frac{m_e}{2T_e}\frac{d}{dx_e}\left(\frac{1}{x_e}\,erf(x_e)\right) + Z\left(1+\frac{m_T}{m_i}\right)\frac{m_i}{2T_i}\frac{d}{dx_i}\left(\frac{1}{x_i}\,erf(x_i)\right)\right]$$

$x_i >> 1$ $\qquad x_e << 1$

$\dfrac{d}{dx_i}\left(\dfrac{1}{x_i}\,erf(x_i)\right)$ $\qquad \dfrac{d}{dx_e}\left(\dfrac{1}{x_e}\,erf(x_e)\right) \approx -\dfrac{4}{3\sqrt{\pi}}x_e$

$12\,\dfrac{1}{x_i^2}$

$$\frac{du}{dt} \approx -\frac{e^2 q_T^2 \ln\Lambda\, n_e}{4\pi\varepsilon_0^2 m_T^2}\left[\left(1+\frac{m_T}{m_e}\right)\frac{4}{3\sqrt{\pi}}\, u \left(\frac{m_e}{2T_e}\right)^{\frac{3}{2}} + \right.$$

$$\left. + Z\left(1+\frac{m_T}{m_i}\right)\frac{1}{u^2}\right]$$

При $u = u_{cr}$:

$$\left(1+\frac{m_T}{m_e}\right)\frac{4}{3\sqrt{\pi}}\, u_{cr} \left(\frac{m_e}{2T_e}\right)^{\frac{3}{2}} = Z\left(1+\frac{m_T}{m_i}\right)\frac{1}{u_{cr}^2}$$

$$u_{cr} = \left[\frac{Z\left(1+\frac{m_T}{m_i}\right)}{1+\frac{m_T}{m_e}}\;\frac{3\sqrt{\pi}}{4}\left(\frac{2T_e}{m_e}\right)^{\frac{3}{2}}\right]^{\frac{1}{3}}$$

Critical energy:

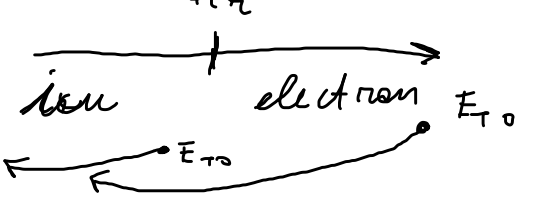
$$\frac{1}{2} m_T u_{cr}^2 = K \cdot T_e$$

$K \approx 20 \div 30$

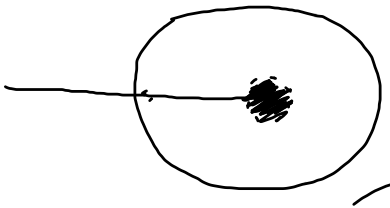
If $E_T > E_{cr}$: slowing down mostly due to el. collisions $\Rightarrow$ el. heating

If $E_T < E_c$: = = = due to ion collisions $\Rightarrow$ ion heating

$E_{T,0} > E_{cr}$



Neutral beam injection



E_{T0} is predominantly determined by the need to have most of the ionization in the core

Dependence: $\rightleftarrows$ machine size / density

Joint European Torus (JET)

$R_0 \simeq 3\ m \quad a \simeq 1\ m$

$n \sim 5 \cdot 10^{19}\ m^{-3} \quad E_{T0} \sim 100\ keV$

$T \sim 5 \div 10\ keV$

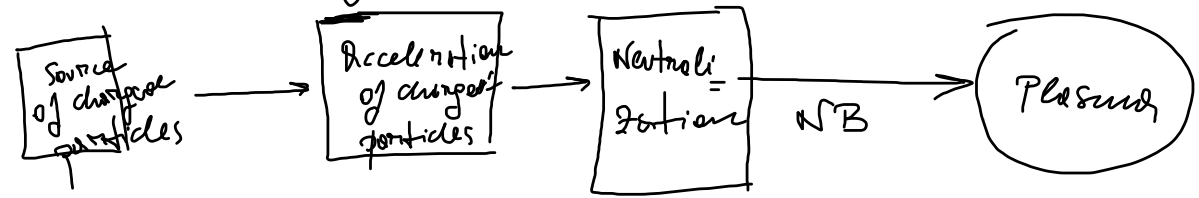
$30 \cdot T \sim 150 \div 300\ keV \quad E_{T0} < E_{critical}$

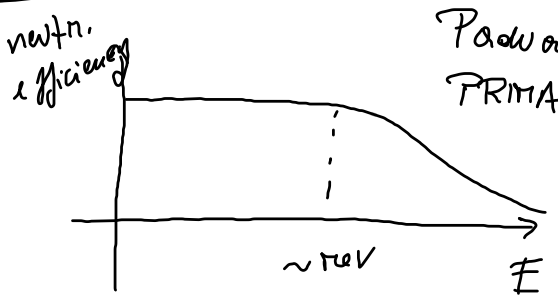
ITER $\quad R_0 \simeq 6\ m \quad a \simeq 2\ m \quad n \sim 10^{20}\ m^{-3} \quad T \sim 10 \div 20\ keV$

$30 \cdot T \sim 300 \div 600\ keV \quad E_{T0} > E_{critical} \quad E_{T0} \sim 1\ MeV$

$E \sim$ MeV $\quad E_{fusion\ process} > E_{critical}$

Neutral Beam Systems





Padova PRIMA

SPIDER

MITICA

$P = I \cdot V$

~A

MV