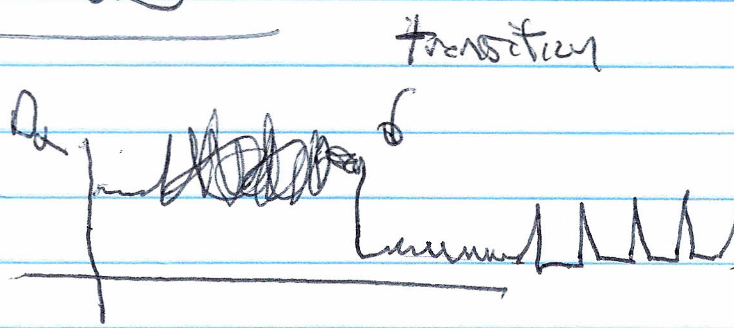
Physics 87 — Class 6

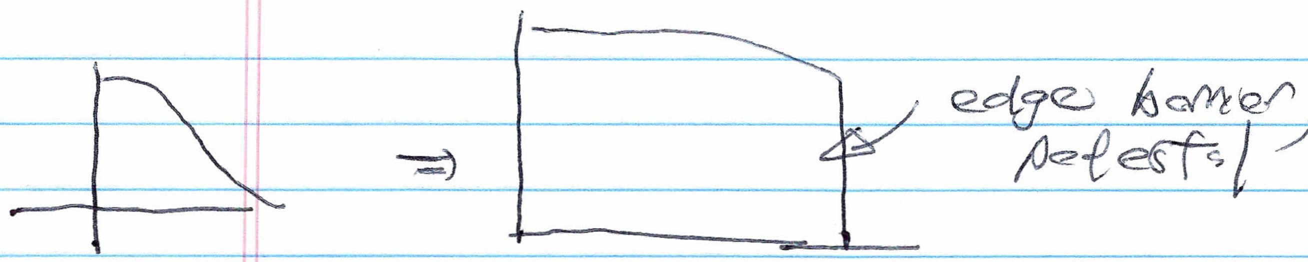
The Tail May Wag the Dog

Recall: measure conization → τ_p



→ $\tau_E \downarrow$ with $P \uparrow$

→ H-mode



$T_{edge} \sim 100$ eV

$T_{edge} \sim 500$ eV – 1 keV

Note: $\nabla T \to 1$ keV in 1 cm.

$\sim 10^3 \times 11{,}604\,°K$

$\sim 10^7\,°$ in 1 cm

{10 M degree in 1 cm}

⇒ <u>that</u> is magnetic confinement!

→ what happens in H-mode?

→ ∇n, ∇T edge steepen

→ turbulence suppressed

transport:

- collisional: $D \sim v_{th} l_{mfp}$
- turbulent: $D \sim (\tilde{V}_{E \times B})^2 \tau_c \sim \tilde{V}_{E \times B} l_{mix}$
  ↳ memory autocorrelation time.

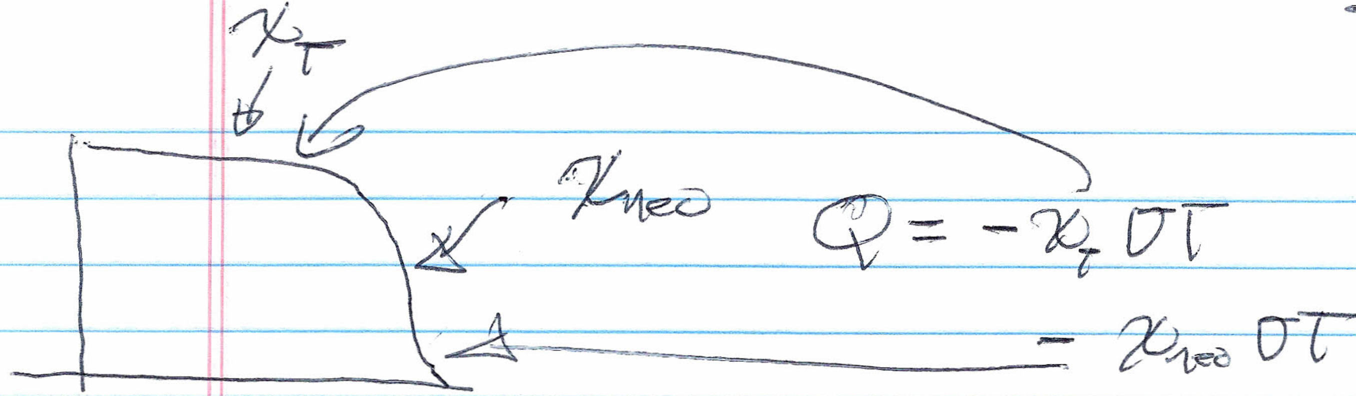
i.e. $M \frac{dv}{dt} = \frac{z}{M} \underline{E} + \frac{z}{M} \frac{\underline{v} \times \underline{B}}{c}$

$t \gg \Omega^{-1}$ $\quad \underline{V} = \frac{c}{B^2} \underline{E} \times \underline{B}$

- $P_{in} \rightarrow Q = -\chi_T \nabla T - \chi_{neo} \nabla T$

$$= -(\chi_T + \chi_{neo}) \nabla T$$

$\chi_T \downarrow$, $\chi_{neo} \ll \chi_T \Rightarrow \nabla T$ steepens.



— phenomenologically, expect sort of:

$$\chi_t \simeq \frac{\chi_0}{1 + \ell^2 (\nabla T/T)^2}$$

$\chi_0 \sim D_{GB}$

n.b. $\chi_0 = \chi_0(\nabla T)$

so

$$Q = -\frac{\chi_0}{1+\ell^2(\nabla T/T)^2} \nabla T - \chi_{neo} \nabla T$$

↓

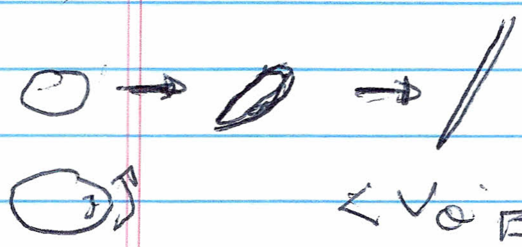
nonlinear in ∇T;
rolls over for large ∇T.

— how?

→ Velocity ($E \times B$) shear layer forms at boundary

T' → T ↑↑

→ shearing destroys extended eddy structures



V_E' vs $1/\tau_c$

$\langle V_{\theta E} \rangle \sim \langle E_r \rangle$

→ shear proportional to ∇P

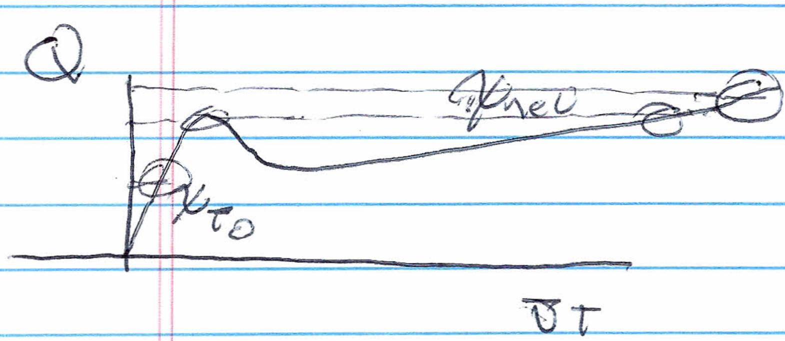
i.e.

$$0 = \frac{q}{M}\langle E_r \rangle + \left(\frac{q}{c} \langle \underline{V} \rangle \times \langle \underline{B} \rangle \right)_r - \frac{\nabla P}{\langle n \rangle}$$

i.e. exceed Q threshold → ∇T, ∇P steepens

→ $\langle V_E \rangle$, $\langle V_E \rangle'$ increase → χ_T drops

→ ∇T, ∇P steepen further, etc. seq.

→ 

→ Transport bifurcation !

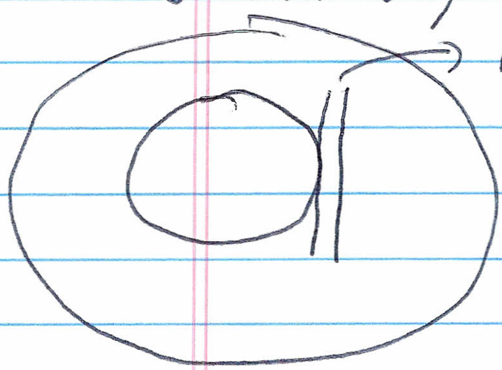
→ Some additional signs :

- hysteresis : $P_{H-L} \neq P_{L-H}$

- $P \leq P_{crit}$ + heat-pulse ⇒ transition

→ How get it ?

→ Boundary control

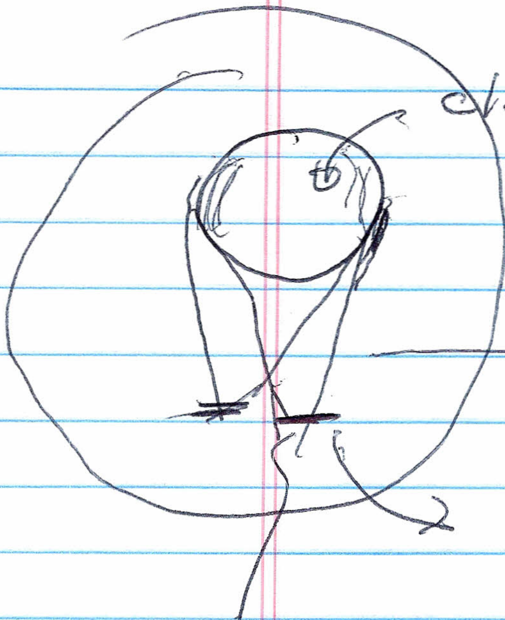


→ limiter ⇒ used to position and control bndry interaction with plasma

⇒ impurities, sputtering ......

vs.

ASDEX } Divertor
PDX



PFC → plasma facing component
⇒ heat load from main plasma "focused" here

N.B.: Plasma-wall interaction removed from vicinity of plasma.

→ Boundary control now central to MFE.

→ Was the H-Mode entirely good news?

not entirely → ELM.

– ELM = Edge Localized Mode

= Edge Relaxation Phenomenon

(small fire in German)

- ELM occurs when $\nabla P_{edge} \approx \nabla P$ for MHD instability

{ surface kink
{ ballooning

- appears due steepening of ∇P as turbulence suppressed.

- relaxation oscillation → build, relax, etc.

- impact:

  - good: impurity removal

  - bad: heat loads.

in ITER 10 MJ energy expelled by ELM (i.e. pedestal blown off).

— ELM / Heatload problem has spawned industry of boundary mitigation

→ RMP — coil, stoch. fields

⇓

→ Pellet pacing

stellarator

→ Pellet injection

→ ergodic divertor ⇒ ⇑

⋮ ⋮

and continued search for new regimes in which to operate machine

→ Q H-mode

→ I-mode

etc.