Why Does Wall Conditioning Affect Plasma Confinement ?

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- Overview and Motivation
- Survey of some experimental results
- Survey of some possible mechanisms
- Potential experiments on NSTX

Overview and Motivation

- Experimentalists and machine operators know that the wall conditions seem to affect plasma confinement in many or most toroidal plasmas

- But there are few systematic studies of this effect, partly due to lack of 2/3-D diagnostics of the limiter/wall and edge plasma, and partly due lack of a theoretical model for this phenomenon

- This effect may have been seen in NSTX already with Boronization, and is motivating some of the planned experiments w/ Lithium coatings or walls

- Understanding the mechanism(s) of this effect could help improve wall conditioning techniques and further improve the performance of NSTX

Survey of Some Experimental Results

- Energy confinement in TFTR improves with wall conditioning of carbon limiters -> supershots
- Confinement further improves in TFTR with Lithium wall coatings and reduced recycling
- Confinement in TFTR drops suddenly from supershot -> L-mode after He gas puffs
- Confinement increases with increased D gas puffs in ohmic plasmas (i.e. Alcator scaling)
- Confinement improves with noble gas puffs in NBI/RF heated RI-mode (like Alcator scaling)
- Confinement w/NBI is not affected by normal D gas puffing or cryopumping (D-IIID, others ?)
- Confinement degrades with strong D puffing especially near density limit and RI (e.g. Textor)

Some Apparently Open Questions

- How many of these results are common to Limiter and Divertor machines, and what is different ?
- How much is dependent on the type of first wall material (e.g. carbon tiles vs. stainless vs. moly) ?
- How much is dependent on the type of wall conditioning used (e.g. Boronization vs. GDC) ?
- Why is improved confinement associated with both high and low edge density (e.g. H-mode vs. SS) ?
- Does the confinement change depend on the type of gas puff used ? (e.g. D vs. He vs. Ne)
- Is this effect associated with the physics of particle confinement vs. energy confinement ? (e.g. pinch)

Survey of Some Possible Mechanisms

1) Changes in wall boundary condition
   - electrical conductivity of wall (e.g. He vs. Li)
   - asymmetry in particle sources or sinks

2) Effects of neutral particle influx
   - radiation + charge exchange cooling
   - increase in collisionality or viscosity

3) Effect on edge plasma parameters
   - change in edge T_e, T_i, n_e, Z_{eff}, or their profiles
   - change in edge radial E or parallel conductivity

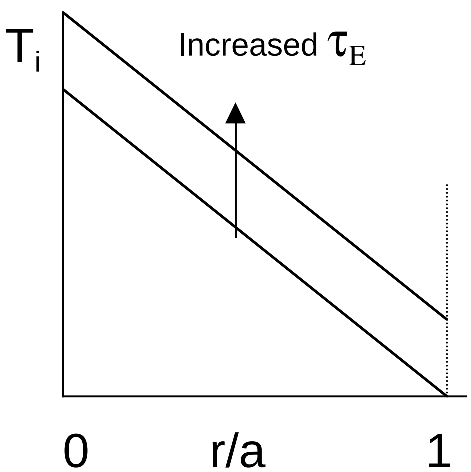
4) Effect on fluctuation-induced edge transport
   - change in electrostatic turbulence or pinch
   - change in edge MHD or magnetic turbulence

5) Other
   - change in ion-to-neutral influx ratio (Cohen)
   - Energy dependent convection (Strachan)
   - Direct core effect (e.g. NBI penetration, H. Park)

Some Potentially Relevant Theories

Kotschenreuther (PoP '95), Bateman (PoP '98):

Global confinement depends on core ITG stability, which depends on edge plasma boundary condition through the ITG critical temperature gradient $L_{T\ crit}$



e.g. $\tau_E \propto T^{0.5}(r/a=0.8)$
[KDBH, TFTR L-mode]

also, τ_E increases with higher edge T_i / T_e & higher edge deuterium dilution

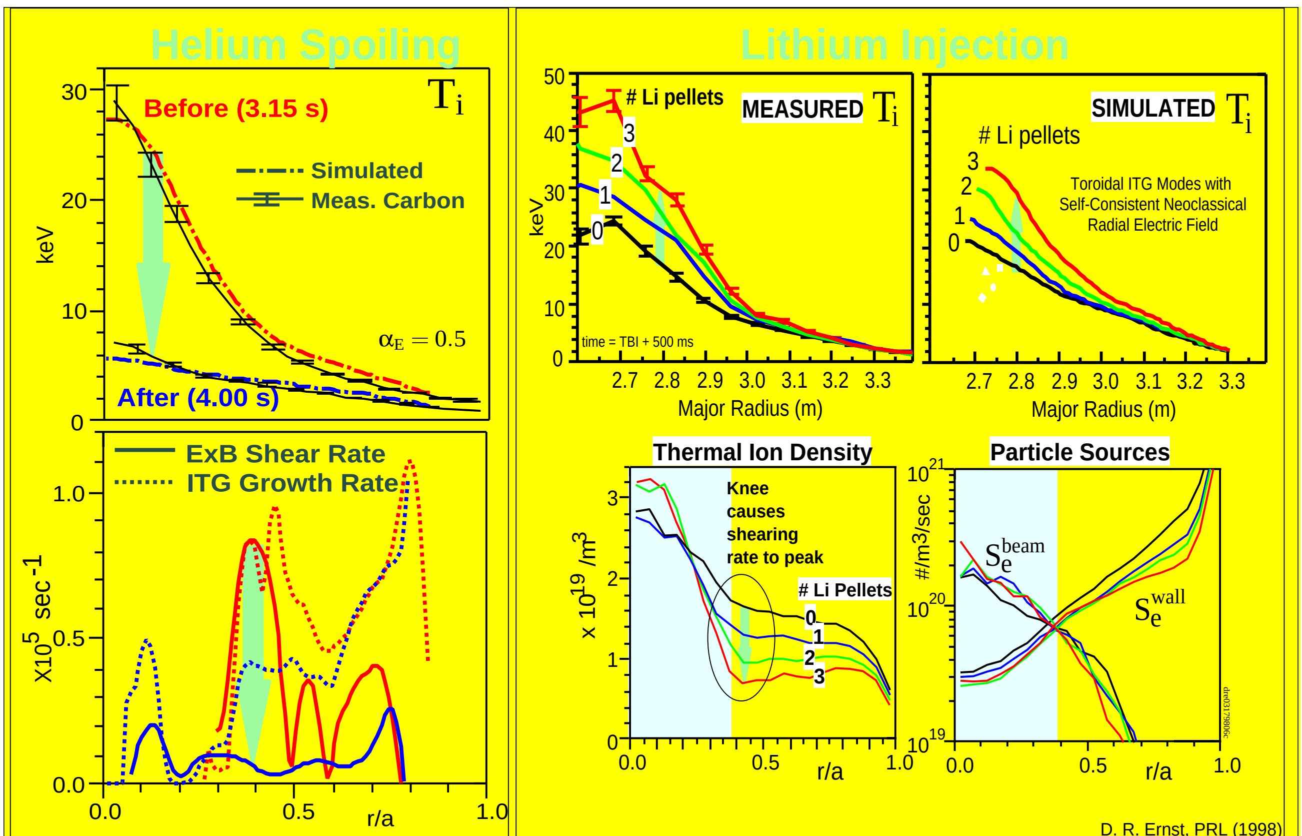
Tokar (PPCF 1999):

Models RI mode as quenching of ITG mode due to increase in Z_{eff} plus density peaking associated with the DTE mode where nq=constant (linear analysis)

Potentially Relevant Theories...cont...

Ernst (PRL '98, PoP '00)

Explains effect of Lithium wall conditioning by "coupling of particle and energy transport through E_r shear", *not* by change in edge ion temperature (there was none !)



Core profiles satisfy $\omega_{E\times B}^{neo} \sim \gamma_{lin}^{max}$ **(ExB shear raises T_i above marginal stability)**

Core ExB shearing rate peaks with density profile and T_i: $\omega_{E\times B}^{neo} \sim \frac{1}{B}\frac{d}{dR}\left(\frac{T_i}{n_i}\frac{dn_i}{dR}\right)$

Strong coupling of particle & energy transport through linear ITG stability and ExB shear

⇨ T_i responds to changes in shape of density profile caused by recycling.

Potentially Relevant Theories...cont...

Rogers (PRL '98), Xu (PoP '00), Myra (Pop '00), etc.

Explicit models of edge turbulence (RBM, DW, R-X) can qualitatively explain edge transport, L->H, etc.

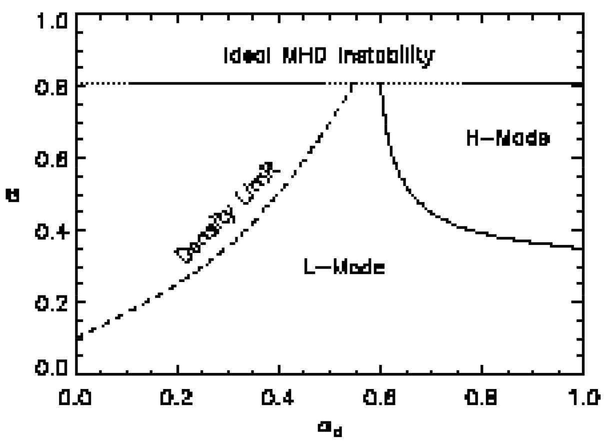


FIG. 1. Edge plasma phase space.

Dimensionless parameters:

$\alpha = -R\, q^2\, \beta/L_p \propto nT$

$\alpha_d = \rho_s c_s t_o/[1+\tau)L_n L_o] \propto T/n^{0.5}$

Zakharov: (APS '99 and '00)

Reduced recycling from the wall reduces "thermo-conduction" to the wall, increasing edge temperature, which increase core temperature, which increases global confinement, and *vice versa*

Potential Experiments on NSTX

General approach:

- Isolate "wall conditioning" effect on confinement by varying plasma-wall interaction (PWI) while keeping other externally controlled parameters constant (e.g. B, I, shape, heating, density, etc)

- Measure carefully edge plasma parameters and edge impurity radiation, and (as much as possible) 2-D wall surface composition and wall heat flux

- Simulate changes in wall conditioning by changes in gas puffing of various species, starting from the cleanest possible wall conditions

- Vary relevant dimensionless parameters, e.g.:
  - Neutrals n_o/n_e, λ_o^*, ν_{cx}/ν_b , etc (Fukuda PPCF'98)
  - Edge plasma α, α_d, ρ_s/R, β, $L_\perp/\rho_s$, $L_\Uparrow/\rho_s$, s, ν, etc.
  - Fractional ionization inside/outside LCFS
  - Spatial asymmetry of sources and sinks

Tentative List of NSTX Experiments

1) Test equivalence of wall conditioning and gas puffing:

- compare plasmas made with unconditioned vs. maximally conditioned walls (esp. neutrals)
- puff gas mix into conditioned case to simulate the neutral influx in unconditioned case
- see if plasma confinement is the same

2) Determine confinement effects of local gas puffing:

- vary puff size and species (D_2, He, CD_4 etc)
- vary symmetry of puff (e.g. 1,2,3 locations)
- vary plasma parameters for fixed gas puffing

3) Explore effects of edge plasma on confinement:

- heat edge with ICRF to increase temperature
- bias walls with "CHI" to change edge flows
- change edge with constant wall conditions, e.g. gaps, shape and q(a) of LCFS, etc.

Potentially Useful Edge Diagnostics

- Wall conditions
  - surface coatings on walls and limiters
  - heat loads on walls and limiters
  - electrical conduction paths

- Neutral and impurity influx
  - 3D emissivity of D_{α}, esp. fraction in/out of LCFS
  - 3D visible emissivity of carbon, oxygen, etc
  - bolometry for edge power balance

- Edge plasma parameters
  - density, electron and ion temperatures, Z_{eff}
  - current density and plasma flow speeds
  - magnetic flux surfaces & electrostatic potential

- Edge fluctuations
  - electrostatic fluctuations (n, φ, T_e)
  - magnetic fluctuations (probe and at wall)
  - low frequency structures (convective cells ?)