Electron transport barriers in the RFX-mod
Reversed Field Pinch with helical equilibrium

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Introduction

• Transport barriers manifest as a significant reduction of the thermal and/or particle transport

• Besides Tokamak and Stellarator, also RFP, subject to ohmic heating only, features electron transport barriers both in the core and at the edge.

• In the plasma core ITBs are the result of a magnetic bifurcation process: from a sea of tearing modes one single saturated mode grows up and conforms the equilibrium of the configuration to its own geometry

• At the edge of RFX-mod, we have robust observation of large electron temperature gradients. Analysis still in an early phase
Internal barrier formation depends on magnetic topology
Reversed Field Pinch and helical equilibrium

q<1 reverses at the edge
Several resonant m=1 MHD modes

When the ratio between the dominant and the secondary m=1 mode amplitude exceeds a threshold the plasma develops a helical equilibrium, characterized by reduced stochastic transport.

Helical equilibrium is a necessary condition to develop thermal electron transport barrier, with strong temperature gradients.
Null q shear in presence of eITBs

The q profile features a null shear point (maximum of q) at the barrier foot

Gobbin, submitted to PRL
Null q shear and flow shear

**Tokamaks**: null q shear related to electron ITBs


Ion ITBs associated to sheared flow

**Stellarators**: ITBs (electron & ion) in CERC regime: large positive Er in the core reduces neoclassical transport.

Enhanced core Er implies a radial region with significant Er shear and turbulence reduction.


**RFX-mod**: electron barriers with a maximum of q (recalling Tokamaks)

MHD simulations predict that the null q shear point corresponds to a high shear of the poloidal flow
Poloidal flow pattern in SHAx

Passive spectroscopic measurements show an inversion of the poloidal flow

Experimentally estimated shear of the order of $10^5$ s$^{-1}$ at $\rho \approx 0.7$

better space resolution necessary to localize the region with the strongest gradient
ITBs develop at low collisionality

ITBs experimentally observed at $n/n_G \leq 0.3$.

actual limit for ITB development or the consequence of a plasma fuelling dominated by wall recycling?

ITBs formed at low collisionality:
Stellarator: possibility to form significant Er related to neoclassical ambipolar fluxes

RFPs: experimentally, magnetic topology triggering barriers through chaos reduction is observed at low collisionality (around $\nu^* = R_\nu/r_\omega \approx 10^{-2}$)
Particle transport in presence of eITBs
A barrier for particles

If pellets reach the plasma core just before the formation of the barrier and particles are ablated in the centre, they are confined inside the barrier.

When pellets are injected with a barrier already developed, particles are ablated outside the barrier and do not penetrate.

Impurities also cannot penetrate the barrier (from LBO experiments).
Reduced particle diffusivity in presence of ITBs

Experimentally: inside the barrier $D$ is reduced by about one order of magnitude $D \approx 5 \text{ m}^2/\text{s}$

From the ORBIT code: diffusion coefficient reduced by about two orders of magnitude with respect to the situation dominated by magnetic chaos

Gobbin, submitted to PRL
Thermal transport in presence of e ITBs
Thermal transport reduction

At the barrier $\chi_e$ is reduced, $\approx 5-10 \text{ m}^2/\text{s}$

Residual transport due to residual magnetic chaos only?
Limit for $L_{Te}$?

$L_{Te}$ never found below $\approx 0.1\text{m}$, indicating that some different gradient-driven mechanism adds to MHD instabilities and limits $\text{grad } Te$. 

**Lorenzini, this workshop poster on Wednesday**
Gyrokinetic calculations point towards microtearing modes

\( \gamma > 0 \) @ \( a/L_{Te} \approx 2 \) \( \rightarrow L_{Te} \approx 0.22 \)

Quasi-linear estimate of the electron thermal conductivity in good agreement with the experimental values, \( \chi \approx 5 \div 20 \text{ m}^2/\text{s} \).

Predebon, submitted to PRL
External electron transport barriers
Observation of edge electron barriers

External barriers appear inside the field reversal radius with $T_e$ gradients of even greater than the internal ones.

As the internal barriers, ETBs are favoured at low collisionality.

ETBs are usually also pressure barriers, with the gradient dominated by temperature.
Relation with magnetic topology

No clear correlation between edge temperature gradient and the MHD mode amplitude.

From field line tracing codes: with ETB the volume of the plasma characterized by short magnetic connection lengths is smaller.
Tokamak and Stellarators feature H-modes

In RFX, we cannot yet say that this is an improved confinement regime, as H-modes are...

...but comparing plasmas at the same current and with similar density with and without ETBs, ETBs correspond to better electron confinement times (about 20%).
Summary and conclusion

- Electron internal transport barriers develop at low collisionality in regimes of reduced magnetic chaos.
- Null $q$ shear at the barrier foot; experimental indications of a corresponding significant shear of the poloidal flow, as predicted by theory.
- Particle and thermal transport decrease: $D \approx 5 \text{ m}^2/\text{s}$, $\chi_{\text{min}} \approx 5 \text{ m}^2/\text{s}$
- Microtearing modes as possible transport drive in addition to residual magnetic chaos.

- Edge transport barriers also observed, with first indications of confinement improvement.

A possible new regime coupling internal AND edge barriers?
No clear correlation between edge temperature gradient and the MHD mode amplitude.

Reconstruction of the q profile: in presence of ETBs, the reversal surface is more external.
... and for impurities

Ni LBO experiments – SXR brightness:

If injected when the barrier is formed, Ni does not penetrate, due to a strong outward pinch close to the gradient region

Menmuir, PPCF 2010
Thermal transport reduction

At the barrier $\chi_e$ is reduced, $\approx 5 \text{--} 10 \text{ m}^2/\text{s}$

LHD,
as a comparision