New Results from C-Mod Internal Transport Barrier Studies

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Internal Transport Barriers (ITBs) in C-Mod arise from steady H-mode plasmas lasting 2 or more energy confinement times when the central power input is low: they are seen in both Ohmic and Off-axis heated ICRF plasmas.

C-MOD plasmas are a unique platform for ITB study:
– No particle or momentum input
– Monotonic q profiles
– Collisionally coupled ions and electrons with $T_i=T_e$

Reduction in particle and thermal transport in the barrier region and core allows the Ware pinch to dominate the transport resulting in strongly peaked pressure and density profiles. Ion thermal transport reduces to neoclassical. **CP1.015 FP1.022**

Control of particle and impurity accumulation is achieved through application of central ICRF heating: TEM stability plays a role. **JO3.005 CP1.004 CP1.015 Ernst, IAEA 2004**
New Results for C-Mod ITBs

Improved performance demonstrated through:

– Maximizing rf input power to the plasma at high field, high current
– Tailored use of central to off-axis rf power input to optimize central plasma parameters.

The function of toroidal magnetic field on ITB formation has been explored with regard to ICRF deposition

The radial extent (ITB foot location) depends on the toroidal field and plasma current: suggests q dependence
Internal Transport Barriers (ITBs) observed in Alcator C-Mod have strongly peaked pressure and density profiles.

The ITB arises gradually after the H-mode is established in off-axis heated ICRF; \(0.02 < \tau_E < 0.03\ s\)

The square root of the visible bremsstrahlung emission yields \(n_e \sqrt{Z_{\text{eff}}}; 1 < Z_{\text{eff}} < 2\)

Core electron pressure from Thomson scattering increases.

3MW off-axis ICRF power, 1MA plasma current gives high pressure in ITB.
Internal Transport Barriers (ITBs) observed in Alcator C-Mod exhibit reduced core thermal transport to ion neoclassical level.

The ITB arises gradually after the H-mode is established if the central power density is lower than the power density at half radius. Core power < 30% of total during ITB in this case.

\[ \chi \] in core \((< r/a=0.5)\) decreases with the application of off-axis ICRF. At \(r/a=0.25\), \(\chi_i, \chi_{\text{eff}}\) reach neoclassical when density peaking becomes noticeable.

The ITB arises gradually after the H-mode is established if the central power density is lower than the power density at half radius. Core power < 30% of total during ITB in this case.
Comparison of the visible bremsstrahlung profile to the square of the density measured from Thomson scattering yields the $Z_{\text{eff}}$ profile.

The ITB profile becomes established between 1 and 1.1 s; The central $Z_{\text{eff}}$ only becomes significant late in the ITB, shortly before a radiative collapse of the H-mode.

$Z_{\text{eff}}$ is between 1 and 2 for most of the profile throughout the discharge.

ICRF Off-axis, No central power
Adding central ICRF power to an established ITB halts the central density rise; the central temperature and pressure double.

Pressure and RF power profiles are shown: The highest pressure peaking occurs with combined central and off-axis power.
Formation of ITBs in Alcator C-Mod with off-axis ICRF is sensitive to the toroidal magnetic field, rf resonance location.

A sharp boundary in toroidal magnetic field where an ITB develops has been seen in off-axis ICRF heated discharges.

ITB presence is characterized by increased density peaking, reduced toroidal rotation velocity.

Red: ITB
Green: no ITB
Magnetic field hysteresis experiments show strong sensitivity to ICRF resonance position for ITB formation.

Magnetic field is ramped down in the red shot, moving the ICRF resonance outward; ITB onset occurs when 40% of the power is inside the ITB radius.

Magnetic field is ramped up in the blue and green shots, moving the ICRF resonance inward; ITB is lost when 60% of the power is inside the ITB radius.

Power distribution calculated using TRANSP with Toric.
The ITB foot location narrows with increasing toroidal magnetic field, decreasing plasma current.

Fitting data from 3 toroidal magnetic field values at different plasma currents suggests that the ITB radius decreases linearly with increasing $q$; $r_{\text{ITB}} = -0.063q_{95} + 0.698$

The foot position is well inside the region where the ICRF power is deposited (Toric calculation).
Summary of New Results:

• The limit for adding central ICRF power to an existing ITB without terminating it has been extended to 1.7 MW from a previous value of 0.6 MW; This did not appear to be an absolute limit even at this power.

• The high field scan was done with high off-axis ICRF power: up to 3MW. This resulted in ITBs with high neutron rate and high stored energy.

• The high added power resulted in central heating and achievement of very high central electron pressure.

• A current scan at high toroidal magnetic field indicated a dependence of the ITB radius on current. Combined with previous field and current scans, a dependence of the foot position with q is indicated.
Future experiments

• Lower hybrid current drive experiments will
  – Use reverse shear to further explore ITBs
  – With LHCD, can we establish barriers with no neoclassical pinch ($V_{\text{loop}}=0$) and no internal particle source?
    – Will control of current profile allow control of ITB location?

• Diagnostic upgrades are providing better fluctuation measurements in the barrier region.