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# The H-mode Power Threshold, Pedestal Width and Plasma Transport in Hydrogen Plasmas in DIII-D

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In recent DIII-D experiments, the H-mode threshold power was found to increase with input torque for both hydrogen and deuterium plasmas as shown in Fig. 1, and the H-mode power threshold for hydrogen plasmas is approximately a factor of 2 larger than in comparable deuterium plasmas. A key result from these experiments is that threshold power for hydrogen discharges with full counter current beam injection is roughly the same as the threshold power for deuterium discharges with co-current beam injection. These results may be significant for ITER, since the L-H threshold scaling is derived from a database that does not take into account the applied torque or plasma rotation. The reduction of the H-mode threshold power with low input torque, determined on DIII-D, is a favorable result for ITER. Companion studies in other hydrogen discharges have shown that the pedestal width and height are comparable to those in deuterium plasmas (Fig. 2), and that the reduction in energy confinement in hydrogen plasmas is largely due to increased core turbulence and transport. Investigating key physics

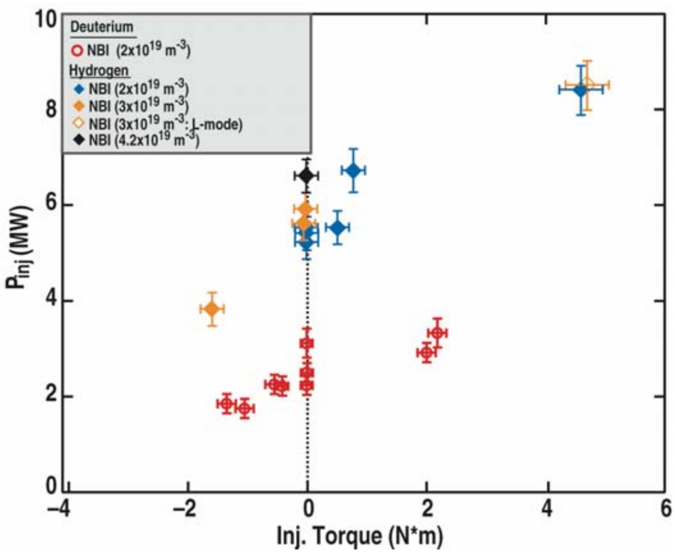


Fig. 1. Injected power required to induce the L-H transition as a function of the injected torque for various target densities. Higher torque data points (>3 Nm) represent all co-NBI discharges in which it was not possible to obtain lower NBI power for the applied torque.

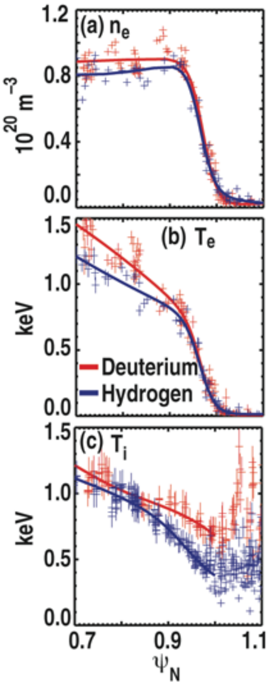


Fig. 2. Comparison of profiles of (a) electron density, (b) electron temperature, (c) ion temperature from D (red) and H (blue) discharges in ITER DEMO configuration.

issues in hydrogen plasmas is vitally important for the first (non-nuclear) operational phase of ITER in which hydrogen (helium) will be used and access to H-mode is important for testing relevant hardware and control systems.

The L–H mode threshold power was evaluated in hydrogen experiments with hydrogen neutral beam injection. The hydrogen concentration [H/H+D] for these experiments exceeded 90% as a result of significant hydrogen plasma and hydrogen neutral beam conditioning prior to the experiments. The input torque was varied by adjusting the mix of co and counter neutral injection. The H-mode threshold in hydrogen discharges increased with input torque much the same as was observed in deuterium discharges [1]. At a density of $3x10^{19}$ and at the highest injected torque (4.5 N-m), there is not sufficient power from the co-current neutral beams to produce H-mode plasmas. In general, in hydrogen plasmas, the H-mode threshold power increases with density (see for example at zero injected torque), but this dependence is less than expected from the H-mode power threshold scaling with density in deuterium ($P_{TH} \propto n_e^{0.73}$) [2].

In a separate experiment to assess the mass scaling of the pedestal width, Δ, the measured width ratio $(\Delta)_H/(\Delta)_D$ was found to be 1.15 where $(\Delta)_H$ and $(\Delta)_D$ are the pedestal widths for H and D, respectively. This ratio is much more consistent with a $\sqrt{\beta_\theta^{ped}}$ scaling, which would predict $(\Delta)_H/(\Delta)_D = 1$, than for a $\rho_{i\theta}$ scaling, which would predict $(\Delta)_H/(\Delta)_D = 0.7$, where $\beta_\theta^{ped}$ is the pedestal poloidal beta and $\rho_{i\theta}$ is the pedestal ion poloidal gyroradius. Normally, the $\beta_\theta^{ped}$ and $\rho_{i\theta}$ parameters are highly correlated for most tokamak operation. The mass difference of H and D provides an opportunity to break this correlation because $\rho_{i\theta}$ scales with ion mass as $\sqrt{M_i}$ whereas $\beta_\theta^{ped}$ has no mass dependence. The experiment was performed by making discharges in H to match an existing D discharge with the ITER shape, $q$ and normalized global beta $\beta_N$. The heating power and density control were adjusted to attempt to match to pedestal temperature and density of the D discharge. In the best matched set of discharges, the pedestal electron densities and temperatures matched to better than 5% and the pedestal ion temperatures matched within about 30%, with the H discharge being the lower discharge on all parameters (Fig. 2). No shrinking of the pedestal width was observed for the H discharge relative to the D discharge.

A further set of experiments examined the scaling of turbulence, transport and confinement with isotope mass by performing L-mode discharges in hydrogen and deuterium with very similar dimensionless parameters ($\rho^*$, $q$, $T_e/T_i$, Mach #, β, collisionality). The results are generally consistent with previous observations that confinement improves with increasing ion mass. Normalized confinement ($\omega_{c,i}{*}\tau_E$) was approximately a factor of two larger in the deuterium discharges. Detailed turbulence characteristics were measured across the profile. Density fluctuation measurements obtained with beam emission spectroscopy (BES) demonstrate an approximately factor of two increase in normalized density fluctuation amplitude in hydrogen, compared with deuterium. In contrast, radial correlation length measurements in hydrogen scale similarly with the ion gyroradius, as observed during the $\rho^*$ scaling in deuterium experiments.

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