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DIMENSIONALLY SIMILAR DISCHARGES WITH CENTRAL RF HEATING ON THE DIII-D TOKAMAK

by

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DIMENSIONALLY SIMILAR DISCHARGES WITH CENTRAL RF HEATING ON THE DIII-D TOKAMAK

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ABSTRACT

The scaling of L-mode heat transport with normalized gyroradius is investigated on the DIII-D tokamak using central rf heating. A toroidal field scan of dimensionally similar discharges with central ECH and/or fast wave heating show gyro-Bohm-like scaling both globally and locally. The main difference between these results and those using NBI heating on DIII-D is that with rf heating the deposition profile is not very sensitive to the plasma density. Therefore central heating can be utilized for both the low- B and high- B discharges, whereas for NBI the power deposition is decidedly off-axis for the high- B discharge (i.e., high density).

INTRODUCTION

The diffusion of heat across magnetic field lines is of fundamental importance to tokamaks. Diffusion processes can be categorized as being either short wavelength or long wavelength. For "dimensionally similar" discharges, defined as having identical values for all dimensionless parameters except the relative gyroradius (i.e., having ν^* , β , q , T_e/T_i , R/a , b/a , etc., the same but not ρ^*), the diffusivity has a very simple scaling: $\chi \propto B^{-1}a^{-1/2}$ for microturbulence or gyro-Bohm-like scaling, or $\chi \propto B^{-1/3}a^{1/3}$ for macroturbulence or Bohm-like scaling.¹ Nearly all theories for diffusion are gyro-Bohm-like; however, along a dimensionally similar path the empirical L-mode tokamak scalings (such as Goldston) have $\tau \propto B^0$ which is slightly worse than Bohm-like.

Comparing dimensionally similar discharges of the same size but different magnetic field should allow one to distinguish between a gyro-Bohm-like or a Bohm-like diffusion process. If the plasma transport is purely diffusive, then the global confinement should scale as $\tau \propto Ba^{5/2}$ for gyro-Bohm-like diffusion or $\tau \propto B^{1/3}a^{5/3}$ for Bohm-like diffusion. A technical difficulty with this experiment is keeping the auxiliary heating profile similar for the low- B and high- B discharges, especially with NBI heating. Central heating with rf power is ideally suited for this type of experiment since the deposition profile is relatively independent of the plasma density.

EXPERIMENTAL RESULTS

For DIII-D, two forms of central rf heating are available to directly heat electrons: 60 GHz ECH and 60 MHz fast wave (FW). The ECH is resonant centrally at 2 T for fundamental absorption and 1 T for second harmonic absorption. The FW in the direct electron heating regime is always absorbed near the plasma center, regardless of the magnetic field, since the damping increases with electron temperature.²

The fast wave current drive (FWCD) database was examined for pairs of shots which were dimensionally similar. Table I shows some dimensionless parameters for the best matched pair of rf discharges. These divertor plasmas are in L-mode and are

Table I
Dimensionless parameters for dimensionally similar discharges
with central rf heating

	$B_T = 1.07$ T	$B_T = 1.99$ T
R/a	2.7	2.7
b/a	1.7	1.8
q_{95}	6.9	6.7
ℓ_i	1.8	1.8
β_p	0.37	0.34
Z_{eff}	3.2	3.3

fueled by deuterium gas puffing. The high- B shot had co-ECCD and co-FWCD while the low- B shot had co-FWCD only. The ratio of rf-to-ohmic power was nearly the same (5:1) for these two plasmas. More than 70% of the total heating power was deposited inside $\rho = 1/3$ for both discharges.

Figure 1 shows the profiles of β , ν^* , T_e/T_i , and the absorbed power fraction for the two rf-heated dimensionally similar discharges. Ion temperature profiles were obtained by pulsing the neutral beams for approximately 10 msec to obtain CER data. The profiles are well matched throughout the plasma. Although not shown, the density and temperature profile scale lengths are also well matched for these two discharges.

Table II shows the heating power, stored energy, and global confinement for these two discharges. The confinement time scaled like $\tau \propto B^{1.2}$, which is slightly stronger than gyro-Bohm-like. Since the global confinement exhibits gyro-Bohm-like scaling, the local transport should also be gyro-Bohm-like. The local transport is determined from a power balance analysis code. The ECH and FW deposition profiles and current drive are calculated by ray tracing codes. For the $B_T = 1.99$ T discharge, a large fraction of the FW power is absorbed centrally by second harmonic heating of the $\approx 2\%$ hydrogen minority. This complicates a two-fluid analysis of the transport, since the partition of the FW power to ions and electrons is not accurately known. Therefore in order to eliminate this uncertainty, a one-fluid transport analysis is performed. The one-fluid heat diffusivity for each discharge was calculated using

$$\chi_{\text{eff}} = - \frac{q_e + q_i}{n_e \nabla T_e + n_i \nabla T_i} \quad (1)$$

The ratio of the χ_{eff} in the 1.99 T discharge to that found in the 1.07 T discharge is shown in Fig. 2. Also shown are the ratios for Bohm-like and gyro-Bohm-like transport scaling. The experimental data for the rf centrally heated plasmas is again clearly much closer to gyro-Bohm-like than Bohm-like for all radii. The rf heating profiles were similar only outside $\rho = 1/3$, which may explain the deviation from gyro-Bohm-like scaling inside that radius, although sawtooth transport may also be an important effect.

DISCUSSION

Dimensionally similar discharges with central rf heating exhibit gyro-Bohm-like scaling both globally and locally. This is in contrast to previous results from DIII-D

FIG. 1. Profiles of dimensionless parameters for two dimensionally similar discharges with central rf heating.

Table II
Global confinement parameters for dimensionally similar discharges
with central rf heating

	$B_T = 1.07 \text{ T}$	$B_T = 1.99 \text{ T}$
P_{rf}	0.90 MW	1.45 MW
P_{oh}	0.16 MW	0.29 MW
W	39 kJ	131 kJ
τ	36 msec	75 msec

with NBI heating where the global confinement time followed Bohm-like scaling or worse for a similar L-mode B -scaling experiment.¹ One difference between these two experiments is that with rf heating the deposition profile is not very sensitive to the plasma density. Therefore central rf heating can be utilized for both the low- B and high- B discharges, whereas for NBI the power deposition is decidedly off-axis for the high- B discharge (i.e., high density). However, when dimensionally similar discharges

FIG. 2. Ratio of 1.99 T and 1.07 T one-fluid heat diffusivity versus normalized radius (solid squares).

with central ICRH were studied on JET, the transport still appeared to be Bohm-like.³ The different experimental results between DIII-D and JET may be due to systematic differences in the operating regimes. For DIII-D the rf power directly heats the electrons resulting in T_e/T_i well above unity, whereas $T_e \approx T_i$ in the JET experiments. In addition, the rf experiments on DIII-D operated at higher safety factor and lower density, and thus higher Z_{eff} than the JET experiments. Future experiments on DIII-D at higher rf power will address these systematic differences.

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