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Isotope effect in improved core confinement plasmas
改善コア閉じ込めプラズマにおける同位体効果

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Isotope effect in improved core confinement including internal transport barriers is reviewed for tokamak plasmas. For ITB in reversed shear plasmas, isotope effect on confinement seems to be small. In positive shear plasmas, more enhanced confinement is generally observed in higher mass number, except for JET Optimized Shear plasmas. Possible reasons for these tendencies are discussed.

1. Introduction

The isotope mass number M of plasma ions is one of the important parameters that would affect plasma behavior including cross-field transport processes. Its effects on energy confinement in OH, L-mode and H-mode plasmas have been studied extensively in many tokamak and stellarator devices. On the other hand, study on its effects on improved core confinement including internal transport barriers (ITBs) seems to be rather limited. This is partly because these plasmas have a wider range of variety in the radial profiles and in confinement properties and then evaluating the effect of M correctly, eliminating effects of other parameters, is not so easy as in OH, L-mode and H-mode plasmas. In this presentation, study on isotope effects on improved core confinement including ITBs is reviewed.

2. Positive shear plasmas

Improved core confinement with peaked density and/or temperature profiles is observed in positive shear plasmas by some methods; counter NB mode in ASDEX, I-mode in TEXTOR, supershot in TFTR, off-axis ICH in Alcator C-Mod, and pellet injection in some devices.

In ASDEX, the counter NB mode was found only in deuterium plasmas and the few attempts to achieve this in hydrogen plasmas were not successful [1]. Also in ASDEX, strong peaking of density profile was observed both in deuterium pellet injection into deuterium plasma and in hydrogen pellet injection into hydrogen plasma, though higher confinement was observed in deuterium.

In TEXTOR I-mode plasmas, up to a 35% increase in the confinement time was observed in deuterium plasmas over hydrogen plasmas, for fixed plasma current and NB power [2].

In TFTR supershot plasmas, isotope effects were studied comparing deuterium NB injection and tritium NB injection. A strong isotope scaling was found such as $\tau_E^{thermal} \propto \langle M \rangle^{0.89\pm0.20}$ and $\chi_i^{ttot} \propto \langle M \rangle^{-2.6\pm0.50}$ for fixed NB injection power [3].

In Alcator C-Mod ICH experiment, only deuterium plasma was used for H minority heating.

Internal transport barriers are observed in NB-heated weak positive shear plasmas on JT-60U (high β_p mode) and on JET (Optimized Shear regime). In JET, comparison between DD plasmas and DT plasmas indicates that core transport and threshold power for ITB formation were similar [4]. In JT-60U, clear ITB was observed only in deuterium plasmas and attempts to obtain ITB in hydrogen plasmas were not successful.

3. Reversed shear plasmas

Electron ITBs are observed with dominant electron heating in reversed shear plasmas on many devices. It is likely that the negative shear is believed to be the dominant factor for the formation of electron ITB and the heating power threshold is very low. Very few attempts seem to be made to investigate isotope effect on this kind of ITB. It seems that electron ITB was observed only in deuterium plasmas on FTU and TCV. In Tore Supra, electron ITB with ICRF minority heating was done both in helium plasma and deuterium plasma, but no systematic comparison is found.

Ion ITBs are also observed with NB heating in reversed shear plasmas on several devices. The ion transport can be reduced to the neoclassical transport level. Deuterium plasmas are used in most devices for this regime.

In JT-60U, the ion ITB was observed in deuterium and hydrogen reversed shear plasmas. A 'box-type' ITB with a very steep T_i gradient was observed in hydrogen plasmas as well as in deuterium plasmas. The threshold power for ITB formation was compared in deuterium and hydrogen plasmas [5]. Though higher heating power was required in hydrogen than in deuterium, it might be attributed to the difference in electron density, which was higher in hydrogen in order to suppress shine through of hydrogen NB.

In TFTR reversed shear plasmas, isotope effects were studied comparing deuterium NB injection and tritium NB injection [6]. No difference on global energy confinement time was observed. More heating power was required for obtaining transition from RS (Reversed Shear) regime to ERS (Enhanced Reversed Shear) regime in tritium than in deuterium.

4. Discussion

For ITB in reversed shear plasmas, isotope effect on confinement seems to be small. This is probably because the negative shear has a dominant role for reducing the transport.

In positive shear plasmas, more enhanced confinement is generally observed in higher mass number, except for JET Optimized Shear plasmas. The reduction of radial transport in this regime is attributed not only to weak magnetic shear but also to density gradient, pressure gradient, ExB shearing rate and so on. Therefore, the isotope effect on transport in L-mode plasmas before entering the improved confinement regime might have a significant role. As is well known, the global energy confinement in L-mode depends on M, for instance in $M^{0.5}$ in ITER89P scaling. It is found that the central density peaking factor $n_{e0}/<n_e>$ is larger in deuterium than in hydrogen [1] in ASDEX Ohmic-heating plasmas. As for the momentum transport, strong dependence on M, $\left\langle \chi_\phi \right\rangle \propto M_{eff}^{-0.8}$ is found in ASDEX L-mode plasmas [7]. The smaller momentum transport may result in higher rotation and higher ExB shearing rate.

References

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