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LHDにおける次元相似性からのエネルギー閉じ込めと熱輸送の同位体効果特性評価
Characterization of isotope effect on energy confinement and thermal transport from dimensional similarity in LHD

山田弘司[1]，居田克巳[2),3)]，田中謙治[2),4)]，關良輔[2]，村上定義[5] 他
YAMADA Hiroshi[1], IDA Katsumi[2], TANAKA Kenji[2],
SEKI Ryosuke[2], MURAKAMI Sadayoshi[3] et al.

[1]東大新領域，[2]核融合研，[3]総研大，[4]九大総理工，[5]京大工
[1] Univ.Tokyo, [2]NIFS, [3]SOKENDAI, [4]Kyushu Univ., [5]Kyoto Univ.

Isotope effect on energy confinement time and thermal transport has been investigated for plasmas with hydrogen (H), deuterium (D), helium (He) and their mixtures in LHD. Stationary uneventful plasmas, which are accompanied by neither ITB nor transition and referred to L-mode, have been assessed here. The date-base has been extended with elaborated documentation in particular effective mass A_{eff} and charge Z_{eff}, compared to the work reported earlier [1] with simpler assumptions. Statistical regression analysis of NBI heated H/D plasmas has indicated that thermal energy confinement time $\tau_{E,th}$ no significant dependence on A_{eff} in the expression of engineering operational parameters;

$$\tau_{E,th}^{scl,HD} \propto A_{eff}^{0.01} Z_{eff}^{-0.11} B^{0.87} n_e^{0.71} P^{-0.85} \quad (1).$$

When the energy confinement time normalized by ion gyro-frequency Ω_i is assumed to be expressed by major dimensionless parameters, this scaling expression is rephrased into the dimensionless expression of $\tau_{E,th}\,\Omega_i \propto A_{eff}^{0.46}\rho_*^{-2.74}$. Identified mass dependence compensates unfavorable negative dependence on mass ($\rho^* \propto (A_{eff}T)^{1/2}/(Z_{eff}B)$) in the gyro-Bohm model $\tau_{E,th}\,\Omega_i \propto A_{eff}^{0}\rho_*^{-3}$. It should be also emphasized that gyro-Bohm-like dependence of ρ^{*-3} remains. The regression analysis including He and its mixture plasmas including ECH heated plasmas has indicated

$$\tau_{E,th}^{scl,mix} \propto A_{eff}^{-0.02} Z_{eff}^{-0.08} B^{0.91} n_e^{0.68} P^{-0.85} \quad (2),$$

which is essentially the same as the expression of NBI heated H/D plasmas (1) and shows a good fitting (see Fig.1). No evident dependence on A_{eff} is robust nature in L-mode plasmas in LHD.

Thermal diffusivity in dimensionally similar plasmas has been compared in order to clarify the peculiarity of isotope effect seen in the energy confinement time. Since the three operational parameters B, n_e, and P are controllable in the experiment, dimensionally identical condition in terms of ρ_*, ν_*, and β can be fulfilled for plasmas with different A_{eff}. With using the confinement improvement factor of $\alpha=\tau_E^D/\tau_E^H$, which is $1/\sqrt{(A_{eff}^D/A_{eff}^H)}$ if gyro-Bohm, the operational conditions for dimensionally similar H and D plasmas are given by the following relation, $B_D=(A_{eff}^D/A_{eff}^H)^{3/4}B_H$, $n_e^D=(A_{eff}^D/A_{eff}^H)n_e^H$, $P_D=(A_{eff}^D/A_{eff}^H)^{3/4}\alpha^{-5/2}P_H$. In results, dimensionally similar pairs have been obtained around $\alpha=1$ as predicted by the discussion about the energy confinement time. Since these pairs of H and D plasmas have the same ρ^*, ν^*, and β, normalized thermal diffusivity χ/Ω_i would be the same based upon whichever neoclassical, Bohm or gyro-Bohm transport plays an essential role. However, χ/Ω_i is improved by a factor of 1.5-2 in D compared with H. This observation is consistent with the A_{eff} dependence identified in the non-dimensional expression of the energy confinement time.

Characteristics of density fluctuation is also discussed in the poster.

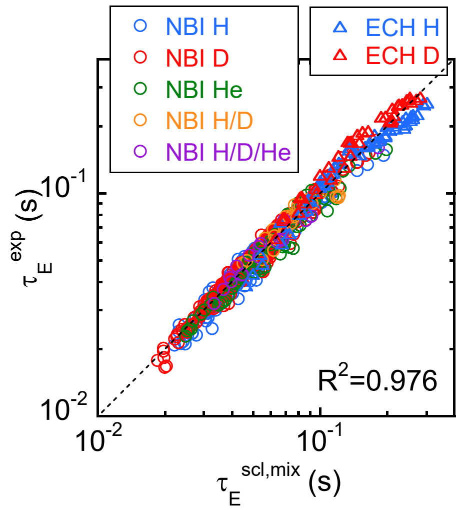

Fig.1 Comparison of thermal energy confinement time in the experiment and the scaling expression (2).

[1] H.Yamada et al., Phys. Rev. Lett. **123**, 185001 (2019).