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Exploration of isotope effects on thermal and particle transport in Large Helical Device

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The latest experimental campaign of the Large Helical Device (LHD) has enabled exploration of isotope effect through comparison of hydrogen(H) and deuterium(D) plasmas. Multiple different properties and mechanisms which are degenerated in a single kind of ion could be resolved in these hydrogenic isotope plasmas. This talk highlights two topics related to isotope effect. One is characterization and quantification of a peculiarity of thermal transport in dependence on normalized gyro radius. Although thermal transport has been widely recognized as gyro-Bohm in tokamak as well as stellarator-heliotron for a single kind of ion, this gyro-Bohm model predicts confinement degradation in D plasmas, which conflicts with major experimental observations. Operational flexibility of LHD enables simultaneous adjustment of normalized gyro radii ρ*, normalized collisionality ν* and beta β, and consequently dimensionally similar plasmas of H and D in all these three parameters can be obtained. Comparison of a pair of dimensionally similar plasmas reveals peculiarity due to different isotope mass. Another topic is investigation of particle transport of hydrogenic ions. Ion transport must be directly coupled with electron transport for plasmas with a single kind of ion, however, this degenerated constraint is resolved in plasmas of compound ions. Identification of difference between H and D ion transports is, in particular, important in order to assess burning efficiency in a future reactor. Bulk charge exchange spectroscopy makes profiles of H and D ion density separately available and the pellet injection system in LHD can fuel H and D atoms into plasma core independently. Particle transport in compound plasmas of H and D is discussed based upon results from these elaborated experiments.

Energy confinement has been widely regarded as gyro-Bohm in tokamak as well as stellarator-heliotron such as [1] $\tau_E^{ISS04}/\tau_{Bohm} \propto \rho^{*-0.79}\,\nu^{*0.00}\,\beta^{-0.19}\iota^{1.06}A_p^{0.07}$.
Although earlier works in medium-sized stellarator-heliotrons have suggested no significant difference in energy confinement time of H and D plasmas, the first deuterium plasma campaign in LHD reveals definitive characteristics of isotope effect in NBI heated plasmas. Purity of isotopes $n_D/(n_H+n_D)$, which is evaluated from the Hα and Dα emissions, is secured at the level of more than 0.77 for D plasmas and less than 0.20 for H plasmas. The magnetic axis position R_{ax}, which is a key geometrical factor, is fixed at 3.6 m in this study. NBI heating power is primarily deposited to electrons and consequently $T_e>T_i$ (statistically P_e/P_i = 4.1±2.0 and T_{e0}/T_{i0} = 1.6±0.3). Thermal energy confinement time gives the regression expression
$\tau_E^{scl} \propto A^{0.15\pm0.02}B^{0.81\pm0.03}\bar{n}_e^{0.65\pm0.02}P_{abs}^{-0.75\pm0.02}$, which shows moderate improvement in D plasmas. This positive isotope dependence contradicts with gyro-Bohm and is similar to the recent result from L-mode plasmas in JET-ILW [2]. The ratio of the thermal diffusivity normalized by Bohm diffusion in dimensionally similar D and H plasmas has been investigated. Figure 1 shows that ratio as a function of collisionality. Electron heat diffusivity stays below 1 (solid horizontal line: gyro-Bohm) and is even lower than 1/√2 (dashed horizontal line: critical point of net improvement) while ion heat diffusivity degrades beyond 1 with ν*.

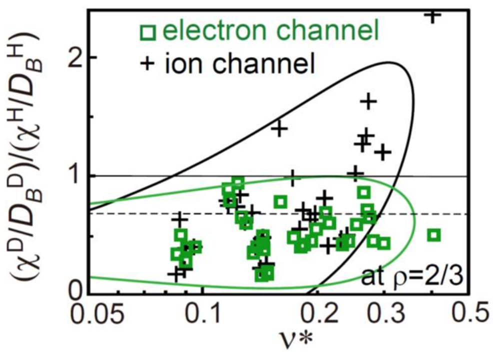

Fig.1 Ratio of normalized heat diffusivity of D and H plasmas. Curves show 95% probability ellipses.

These results have shown definitively that the gyro-Bohm nature is violated in the comparison of H and D plasmas in a large scale heliotron. Isotope effect on particle transport as well as relevant theoretical approach [3] is also discussed.

References

[1] H.Yamada et al., Nucl. Fusion **45** (2005) 1684.
[2] C.Maggi et al., Plasma Phys. Control. Fusion **50** (2018) 014045.
[3] M.Nakata et al., Phys. Rev. Lett. **118** (2017) 165002.