Hydrogen isotope effect on multi-scale turbulence and its role on transport in Large Helical Device

T. Kinoshita [1], K. Tanaka [1, 2], T. Tokuzawa [2,3] Y. Ohtani [4]
[1] Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Kasuga, 816-8580, Japan
[2] National Institute for Fusion Science, Toki, 509-5292, Japan
[3] The Graduate University for Advanced Studies, SOKENDAI, Toki, 509-5292, Japan
[4] National Institutes for Quantum and Radiological Science and Technology, Naka, 311-0193, Japan
e-mail (speaker): t.kinoshita@triam.kyushu-u.ac.jp

Hydrogen isotope effects are essential for the prediction of future fusion reactor operation. In Large Helical Device (LHD), isotope effects of plasma performance are extensively studied. In this study, the systematic survey of turbulence and transport were performed in hydrogen (H) and deuterium (D) plasmas. The electron-scale turbulence ($\rho_i k$~3–4) was measured by backward scattering[1], and the ion-scale turbulence ($\rho_i k$~0.3–0.5) was measured by two dimensional phase contrast imaging[2].

In the series of experiments, two 0.7MW 154GHz electron cyclotron heating (ECRH) was used, then the averaged electron density ($n_{e\ ave}$) was scanned from $0.5 \times 10^{19}\mathrm{m}^{-3}$ to $4.5 \times 10^{19}\mathrm{m}^{-3}$. The magnetic configuration was fixed at magnetic axis position 3.6m, magnetic field at 2.75T. The purity of hydrogen gas and deuterium gas was more than 85% in each plasma. Figure 1 shows the density dependence of plasma parameters and turbulence levels. The averaged electron temperature ($T_{e\ ave}$) and the averaged ion temperature ($T_{i\ ave}$), are higher in D plasma as shown in (a) and (b). The density peaking factor (PF_{ne}) is lower in D plasma as shown in (c) That is, density profiles are hollow both in H and D plasma. The lower PF_{ne} in D plasma indicates hollower density profile in D plasma. As shown in (a)-(c), $T_{e\ ave}$ monotonically decreases with increase of $n_{e\ ave}$, on the other hand, $T_{i\ ave}$ and PF_{ne} does not show monotonically change. $T_{i\ ave}$ has a maximum and PF_{ne} has a minimum at $n_{e\ ave} = 1.7 \times 10^{19}\mathrm{m}^{-3}$.These results suggest ion and particle transport changes at $n_{e\ ave} = 1.7 \times 10^{19}\mathrm{m}^{-3}$. We call this density as the transition density of isotope effects (n_{ts})[3]. At $n_{ts} < n_{e\ ave}$, the difference of $T_{e\ ave}$, $T_{i\ ave}$ and $n_{e\ ave}$ between H and D plasma become larger suggesting that the isotope effects become apparent in this regime. As shown in (d), the electron-scale turbulence decreases with increase of $n_{e\ ave}$ and there is no difference in H and D plasma. On the other hand, clear difference of ion-scale turbulence level is found as shown in (e). At $n_{ts} > n_{e\ ave}$, ion-scale turbulence level is reduces with decrease of $n_{e\ ave}$, and is slightly higher in D plasma. At $n_{ts} < n_{e\ ave}$, ion-scale turbulence level increases with increase of $n_{e\ ave}$, and is clearly lower in D plasma. The density dependence of ion-scale turbulence is similar to the density dependence of PF_{ne}. This suggests that density profile is one of the key parameter of ion scale turbulence and its isotope effects.

Simulation study indicates stronger collisionality stabilization of trapped electron mode (TEM)[4] in D plasma and stronger stabilization effects due to ExB shearing rate[5]. At $\rho = 0.6$~0.8, ion-scale turbulence is dominant instability, and is likely to be ion temperature gradient mode (ITG)[6]. The stronger stabilization of TEM do not account for the observation. ExB shear was almost identical both in H and D plasma. Gyrokinetic linear analyses showed linearly stable in D plasma[6]. One possible interpretation was stronger ExB shear stabilization effects in D plasma. Secondly, hollower density profile reduces growth rate in the present operational regime of LHD[7]. This is another possibility. However, at $n_{ts} < n_{e\ ave}$, ion scale turbulence increases with increase of density (increase of collisionality in this datasets) and with decrease of T_e/T_i. These observations are against fundamental characteristics of ITG. More detail investigations are necessary for the understanding of isotope effects and roles on ion scale turbulence.

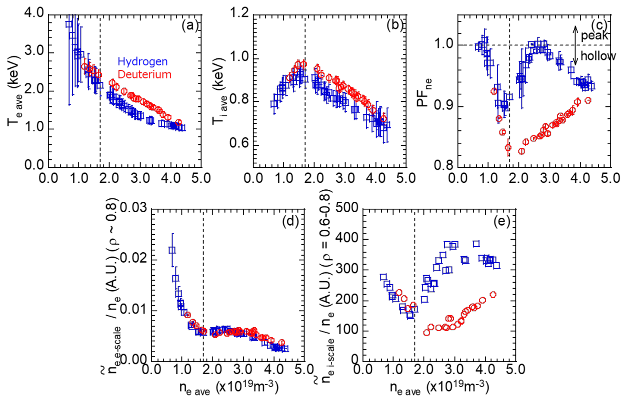

Figure 1 Electron density dependence (a) electron temperature, (b) ion temperature, (c) peaking factor of electron density, (d) electron-scale turbulence and (e) ion-scale turbulence. In (a) and (b), values are averaged at $\rho = 0$~1.0, in (c), the peaking factor was defined as the value between $\rho = 0.2$ and 0.6. The dash line indicate that the transition density ($n_{ts} \equiv n_e = 1.7 \times 10^{19}\mathrm{m}^{-3}$).[3]

Reference

1 Tokuzawa T *et al*, 2021 *Rev. Sci. Instrum.* **92** 043536
2 Tanaka K *et al*, 2008 *Rev. Sci. Instrum.* **79** 10E702
3 Kinoshita T *et al*, *Plasma Phys. Ctrl. Fusion* submitted
4 Nakata M. *et al*, 2017 *Phys. Rev. Lett.* **118** 165002
5 Garcia J. *et al*, 2017 *Nucl. Fusion* **57** 014007
6 Tanaka K *et al*, 2020 *Plasma Phys. Ctrl. Fusion* **62** 024006
7 Nakata M *et al*, 2019 *Plasma Phys. Ctrl. Fusion*, **61** 014016