# Isotope effects on transport in Compact Helical System

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Isotope effects on transport between hydrogen (H), deuterium (D) and tritium (T) are important to predict the performance of fusion reactor. In tokamak, different characteristics of isotope effects between hydrogen and deuterium are reported. In deuterium plasma, H mode threshold power becomes lower and electron and ion thermal diffusivities becomes lower as well[1]. While in helical plasmas, improvement of the transport in deuterium plasma is very modest. In ECRH heating plasma of W-7AS, the stored energy higher by 20% in D is reported at the same density regime[2]. However, due to the limit of the data set in helical devices, isotope effects on transport have not yet been clearly shown from experiment. Comparison experiments in D and H plasmas were done in Compact Helical System (CHS) at National Institute for Fusion Science in 1998-1999. The data are mined and analyzed for isotope effects study in helical devices. This study also aims to predict the transport characteristics of deuterium plasma in the Large Helical Device (LHD) planned from 2016.

Fig.1 shows difference of time evolution in D dominant and H dominant plasma. Toroidal magnetic field was 0.9 T, magnetic axis 92.1cm, and the plasma was attached to a wall of vacuum vessel on the inboard side. After production of 50.4GHz ECRH, plasma is heated by 200kW neutral beam injection. Injection beam species is hydrogen.

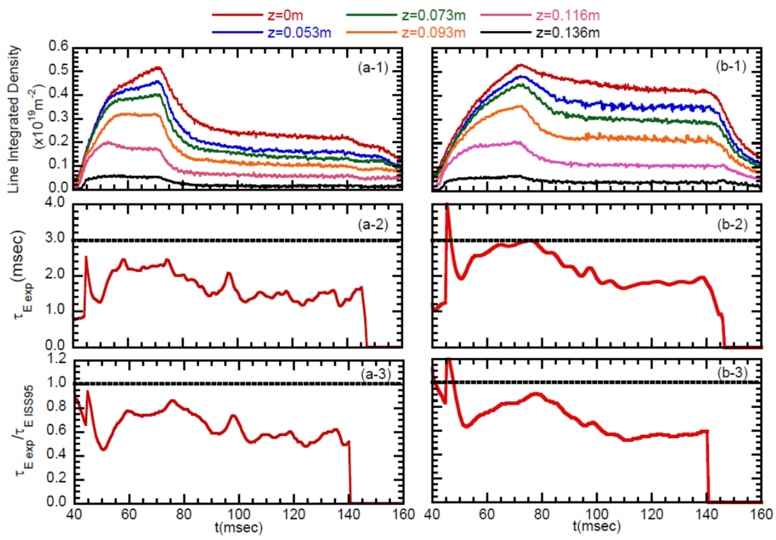


Fig. 1 Comparison of discharge in H dominant (a-1,2,3) and D dominant (b-1,2,3) plasma. (a-1) (b-1) line integrated density, (a-2) (b-2) global energy confinement time and (a-3) (b-3)H factor. Z in (a-1) and (b-1) are vertical position of horizontally viewing interferometer chord. Z=0 is chord at plasma centre, z=0.053, 0.073, 0.093, 0.116, 0.136 correspond to tangent position of ρ=0, 0.35, 0.42, 0.49, 0.55, 0.62, 0.77, 0.91. $0.5\times10^{19}m^{-2}$ at Z=0m, correspond to line averaged density $1\times10^{19}m^{-3}$ for path length 0.5m of the chord.

Then, H and D gas for plasma production were switched in the series of shots. As shown in Fig.1 (a-2) and (b-2), global energy confinement time ($\tau_E$) increases only by about 20% in D dominant plasma. This enhancement almost disappears when normalized by ISS95 scaling. But clear difference of density decay time is observed. The decay time is determined by particle confinement and fuelling. Gas puff was switched off at 70ms, but the wall recycling continues fuelling. The difference of the decay time is clearer at the chord closer to the center (at smaller z), where effects of the wall recycling are smaller. This suggests difference close to plasma center is due to difference of particle transport rather than difference of the recycling. However, the decay time of central chord (z=0) is too much. It is 20ms in H dominant and 120ms in D dominant plasma. Factor six difference is unlikely to be caused by the difference of the particle transport only. It is likely that higher recycling rate also causes longer decay time in D dominant plasma.

Density modulation experiments are done to study particle transport. From radial propagation of modulated density, diffusion coefficient (D) and convection velocities (V), where $\Gamma = -D\nabla n_e + n_e V$ , are separately estimated. Estimation of D and V are independent of absolute value of the ionization rate. Only penetration length of the particle source is necessary[3]. This is very powerful to compare particle transport under different wall condition like Fig.1. Density modulation experiments were widely done in LHD[4]. The detail analysis procedure is described in ref.[4]. For this analysis, model of spatial profile of D and V are necessary as fitting variables . Here, we used three fitting variables. One spatial constant D, the other two are $V_{core}$ at ρ=0.5 and $V_{edge}$ at ρ=1.0. Convection velocity is zero at ρ=0, then increases linearly to $V_{core}$ at ρ=0.5 then it changes linearly from ρ=0.5 to $V_{edge}$ at ρ=1.0. Modulation frequency was 100Hz. A 100Hz was low enough to have a phase shift and high enough to have several periods in analysis time windows. In ref [4], D and V are determined to fit both modulation and background equilibrium profiles. But in this analysis, fitting was done only for modulation components. This is because in CHS, particle fuelling from NBI is large and affects density profile in addition to transport effects.

Figure 2 shows temporal evolution of line averaged density in modulation experiments. By changing external fuelling rate, low ($0.8\text{-}2\times10^{19}m^{-3}$) and high ($2\text{-}4\times10^{19}m^{-3}$) density shots are obtained in H and D dominant plasma. Same density regime was tried, however, in D dominant plasmas, density did not reduce less than $1\times10^{19}m^{-3}$. This suggests recycling is higher and particle confinement is better in D dominant plasma. This is similar to observations in Fig.1. Figure 3 shows spectrum of around Hα and Dα. Fueling ratio D/(H+D)x100(%) is estimated from intensity ratio of Hα and Dα. In low density shot, fueling ratio is 11% in H dominant plasma and 63% in D dominant plasma, in high density shot 19% in H dominant plasma and 82% in D dominant plasma.

In order to survey density dependence of D and V, analysis windows are selected in a single shot. Each analysis window covers 4–10 periods (40-100ms) to keep density around within +-20% of averaged values. These analysis windows are long enough to determine modulation amplitude and phase from correlation analysis. Figure 4 shows radial density profiles from interferometer data. Profiles are calculated every 1msec and accumulated for analysis time window. As shown in Fig.4, difference of density profiles is seen in low density regime, but almost no difference is seen in high density regime. Figure 5 shows density dependence of D and V. Horizontal error bar indicates the density regime of analysis time window. Vertical error bar indicates fitting error of the analysis. The difference of estimated D and V is seen at $n_{e\_bar}<2x10^{19}m^{-3}$, and almost no difference is seen at $n_{e\_bar}>2x10^{19}m^{-3}$ as well as density profiles in Fig.4. Diffusion coefficients show negative density dependence as shown in Fig.5 (a). This is similar to the negative collisionality dependence observed in LHD[4]. At $n_{e\_bar}<2x10^{19}m^{-3}$, diffusion coefficients becomes clearly lower in D dominant plasma than H in dominant plasma indicating improvement of particle transport. The modeled D is spatially constant, but, modulation amplitude is mainly localized at ρ>0.5. Thus, this improvement mainly comes from ρ >0.5. Figure 1 suggests better improvements inner region, but, in this analysis, it is difficult to state about difference of the diffusiveities at ρ<0.5. Convection velocity at ρ=0.5 increases outwardly at $n_{e\_bar}<2x10^{19}m^{-3}$ in H dominant plasma. This tendency is also similar to LHD results, where core convection increases outwardly with decrease of collisionality at magnetic axis ($R_{ax}$) is outer than 3.6m [4]. This can be explained by the outward convection due to neoclassical thermo diffusion. While in D

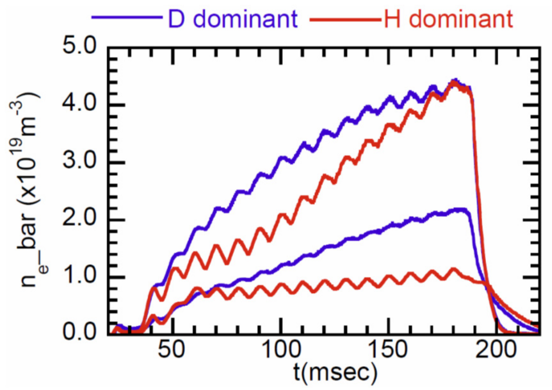


Fig.2 Time trace of line averaged density in modulation experiments

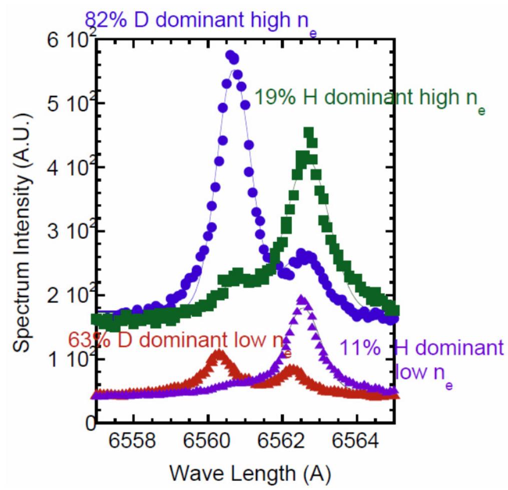


Fig.3 Comparison of Hα and Dα spectrum.

dominant plasma, V (ρ=0.5) at $n_{e_bar}<2x10^{19}m^{-3}$is more inwardly directed than the one at $n_{e\_bar}>2x10^{19}m^{-3}$. In LHD, such tendency was seen at very inwardly shifted configuration ($R_{ax}$=3.5m), where magnetic hill is dominant. However, in this experiment, magnetic property is same in H and D dominant plasma. The mechanism of density peaking observed in D dominant plasma of CHS is different from ones in H plasma in LHD at $R_{ax}$=3.5m. Neoclassical effects does not cause density peaking. In D dominant plasma, anomalous effects can cause density peaking.

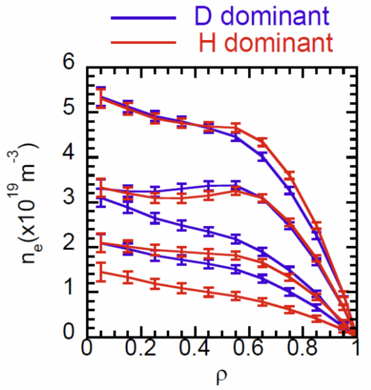


Fig.4 Density profiles in H and D dominant plasma

From results obtained, the following are concluded. Isotope effects of particle transport in CHS is seen only in low density region at $n_{e\_bar}<2x10^{19}m^{-3}$. In this region, diffusion becomes lower and V (ρ=0.5) becomes more inwardly directed. This suggests that with same fueling, density becomes higher in D dominant plasma, and density profiles becomes more peaked in low density region. The peaked density profile might be favorable to increase beam deposition in central region, which is realized in high $T_i$ discharge in LHD[5]. However, better particle transport may be sensitive to wall recycling effects. Improvement of the confinement due to larger generation of zonal flow in D plasma is theoretically expected[6]. Such phenomena is more evident low collisionality regime due to smaller damping of zonal flow. This is one of possible interpretation of obtained results

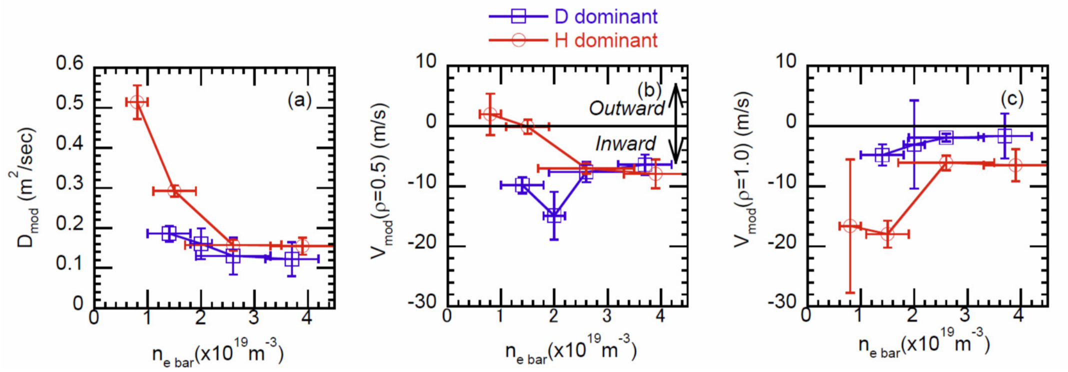


Fig.5 Density dependence of (a) D and (b),(c) V in H and D dominant plasma

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