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A study of impurity transport in hydrogen and helium plasmas on LHD

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I. Introduction

A combination of impurity pellet injection [1, 2] and spectroscopic method has been applied on the Large Helical Device (LHD) in order to understand the particle transport behavior in core plasmas. For this purpose, carbon pellets were injected into NBI-heated plasmas, and the transport coefficients D and V were inferred by a bremsstrahlung measurement with high-spatial resolution. The information on the impurity transport from the plasma center to the edge has been successfully obtained by the parallel arrays with 2×40 channels.

In hydrogen plasmas, the magnitude of spatially constant diffusion coefficient D is typically an order of magnitude larger than the neoclassical value, and dependences of the D on the impurity ion charge state and the electron density were weak. The inward convective velocity V of impurity ions, on the other hand, had strong dependences on both the impurity ion charge state and the electron density, of which the gradient was significant [3]. In this paper, the dependences of transport coefficients D and V on the charge state of bulk ions are compared in the collisional regime of hydrogen and helium plasmas on LHD.

II. Experimental Setup

The impurity pellet injector is installed for the purpose of direct deposition of impurity particles inside the last closed flux surface (LCFS) [4]. The impurity pellet is directed towards the plasma center on the equatorial plane from an outboard side of the torus. In order to investigate the behavior of injected carbon ions, the visible bremsstrahlung diagnostic using an interference filter and PMTs having high spatial (5cm) and temporal (0.1ms) resolutions was installed on LHD [5]. The filter has a central wavelength of λ=536.6nm and a full width at half maximum of 6.2nm. No strong emission line emitted near the wavelength region. As shown in Fig.1, the poloidal cross-section of LHD plasma is fully covered by 40 horizontal viewing chords of the bremsstrahlung diagnostic. As another diagnostic, a visible spectrometer with CCD detector is used to eliminate the contribution of emission lines at the same time. A single scan of the CCD frame requires 40ms interval. The contribution of emission lines to the PMT signal detected through the interference filter can be evaluated taking into account the spectrum recorded with the CCD.

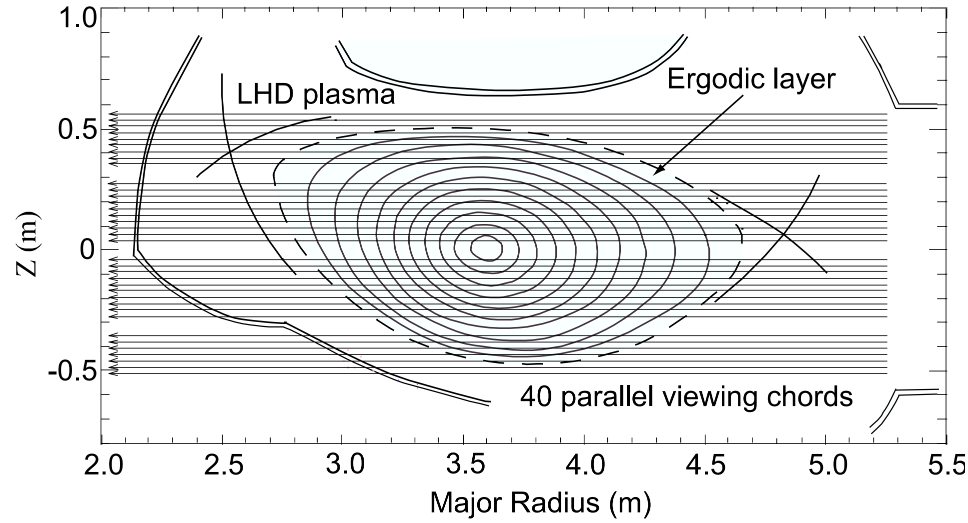

Fig. 1 Cross-sectional view of 40 chords per one poloidal section for the visible bremsstrahlung measurement and the configuration of LHD plasma with R_{ax}=3.6 (m).

III. Experimental Results

Cylindrical pure carbon pellets with (2.3-7.2)×10^{19} particles/pellet were injected into a steady phase of hydrogen and helium discharges with R_{ax}=3.6m. The plasmas are heated by NBI (P_{NBI}~7MW), and the carbon pellets are mostly ablated in the vicinity of ρ=0.65. Using a diffusive/convective model with a cylindrical approximation, the carbon transport was analyzed using one-dimensional impurity transport code [6] with a time step of 0.5ms. In the simulation, time evolutions of electron temperature were given by the data of ECE diagnostic. The transport coefficients D and V were determined by minimizing the total residual error between the measured and calculated intensities from z=-2.6 to z=-39.1cm. Here, it is assumed that the changes in electron density and effective charge profiles are brought only by the carbon ion transport with unchanged bulk ion transport. The analysis shows that, in hydrogen plasmas with R_{ax}=3.6m, the D have a spatially constant value and the inward V is required only in the region ρ>0.6 where electron density gradient exists. The same spatial structure of the transport coefficients in hydrogen plasmas was also adapted to the analysis for helium plasmas. Figure 2 shows the comparison of time evolutions between measured and calculated bremsstrahlung intensities in hydrogen and helium plasmas. The D and V were examined for various sizes of the injected carbon pellets in hydrogen plasmas. No difference in the obtained D and V was observed for different carbon pellet sizes. The density dependences of the inferred D and V at ρ=0.8 are summarized in Fig.3 for both discharges. Uncertainties of the obtained D and V are estimated to be 0.05m^2/s and 0.2m/s. It is found that the inward V in helium plasmas is lower than that in hydrogen plasmas by a factor of two, as seen in Fig.3 (b), whereas D is independent of the species of bulk ions (see Fig. 3(a)).

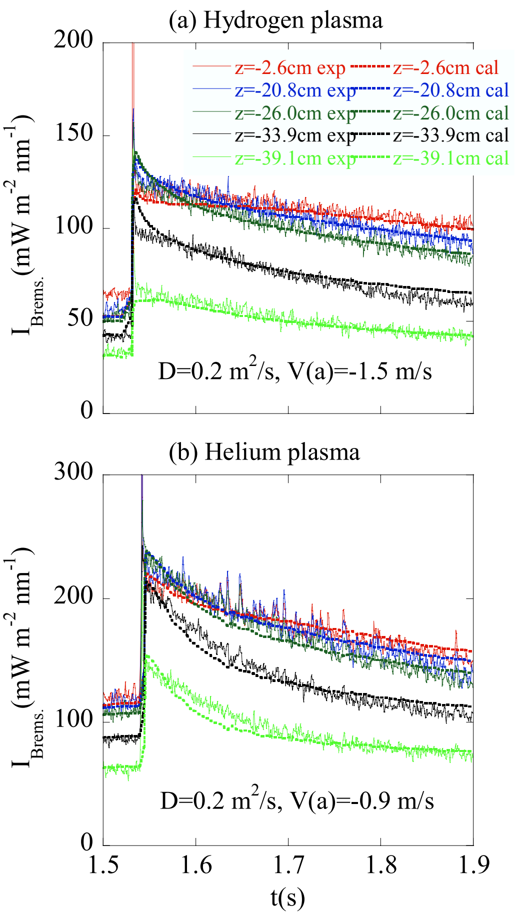

Fig. 2 Comparison of time evolutions between measured (solid lines) and calculated (dotted lines) bremsstrahlung intensities in (a) hydrogen and (b) helium plasmas.

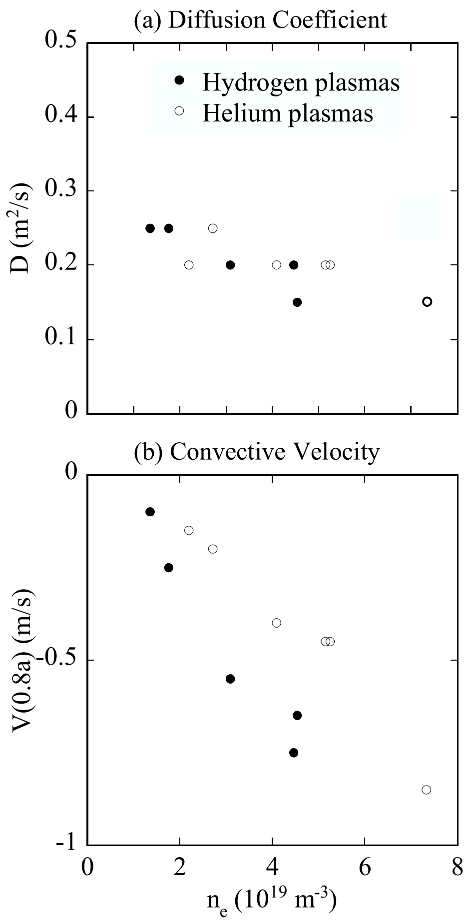

Fig. 3 Comparison of (a) diffusion coefficient and (b) inward velocity at ρ=0.8 as a function of line-averaged electron density in hydrogen (●) and helium plasmas (○).

VI. Discussions

According to neoclassical theory in collisional regime, the impurity ion flux Γ_{imp} is given by the following equation, if the impurity ion temperature gradient is negligible;

$$\Gamma_{imp} = -D_{imp}\frac{\partial n_{imp}}{\partial r} + n_{imp}V_{imp} = -D_{imp}\frac{\partial n_{imp}}{\partial r} + \frac{D_{imp}}{T_{imp}}\left(\frac{q_{imp}n_{imp}}{q_i n_i}\right)\frac{\partial p_i}{\partial r}, \quad (1)$$

where n, q and p stand for the density, charge state and pressure, respectively. The subscript *imp* and *i* denote impurity and bulk ions. Furthermore, although the inward flux (V<0) in the impurity ion flux is expected to be driven by the bulk ion density gradient, the bulk ion temperature gradient term contributes to the outward flux (V>0). Then, the inward flux of impurity ions can be replaced as follows [7];

$$V_{imp} = D_{imp}\left(\frac{q_{imp}}{q_i n_i}\right)\frac{\partial n_i}{\partial r} . \tag{2}$$

The Eq. (2) indicates that the inward flux is appeared by the density gradient of bulk ions. If the $n_i(r)$ is reflected by $n_e(r)$, the inferred spatial structure of the inward V shows a good agreement with the bulk ion profile, as shown in Fig. 4(a). Figure 4(b) shows the relation between the inward V and the electron density gradient at ρ=0.8 in hydrogen plasmas. It is clearly seen that the inward V is a strong function of the $\partial n_e/\partial r$.

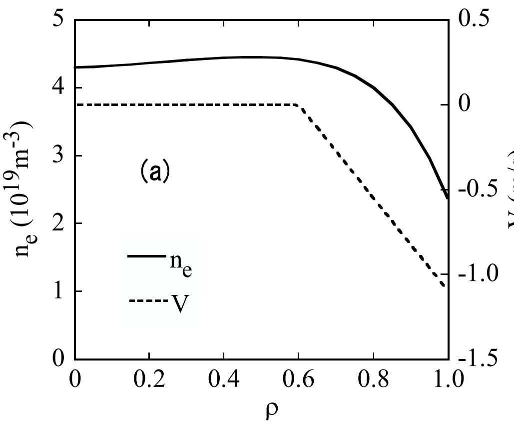

Fig. 4(a) Spatial structure of inward V and electron density profile in typical hydrogen plasma.

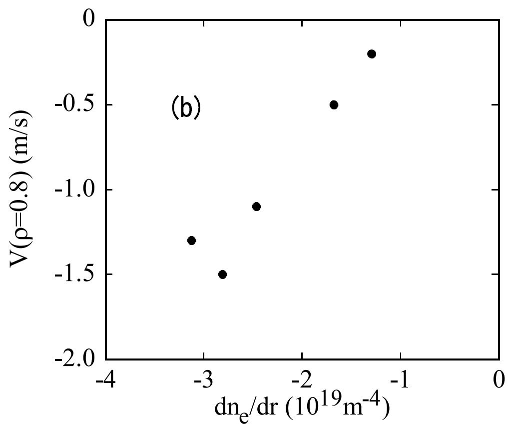

Fig. 4(b) Relation between inward V and electron density gradient at ρ=0.8 in hydrogen plasmas.

The Eq. (2) also suggests that the inward flux is inversely proportional to the charge state of bulk ions q_i. Seeing the present results in Fig.3 (b), the inward V in helium plasmas has roughly a half value of hydrogen plasmas. The difference of the inward V between both plasmas can be possibly explained by the neoclassical effect.

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