

## Heat and particle transport in hydrogen and helium

### ECRH plasmas on LHD

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### 1. Introduction

The influence of isotope mass effects on the confinement property is observed with improvement of the energy confinement in many tokamaks. Mass dependence of the confinement properties is one of the mysteries in the magnetic confinement fusion devices. The energy confinement time  $\tau_E$  generally increase with mass  $M$ :  $\tau_E \propto M^a$  where the exponent  $a$  is greater than 0 in tokamaks [1]. While in stellarator, clear mass dependence of the confinement property was not reported in ECRH plasmas [2]. Most models such as gyro-Bohm diffusion model indicate that the energy confinement deteriorate with the increase in the isotopic mass related to the increase in the Larmor radius. These models contradict the experimental dependence of the confinement on mass in tokamaks. To clarify the mass effects on the confinement in helical devices, the confinement property of hydrogen and helium plasmas were compared on the Large Helical Device (LHD).

### 2. Comparison of Heat Transport

Comparative experiments of heat transport in hydrogen and helium plasmas were performed on LHD. Figure 1 shows the temporal evolution of the ECRH injection power, the ratio of hydrogen to helium H/(H+He), the line averaged electron density, the electron and ion temperature. 1 MW ECRH was applied on hydrogen and helium plasmas to investigate dynamic/steady transport properties. Plasmas were sustained by only ECRH, without NBI, to form helium rich plasmas for helium plasma experiments. Helium glow discharge cleaning was done for helium plasmas. A ratio of H to He are approximately 90% in “hydrogen” and 30% in “helium” discharges, respectively. While there is no significant difference in the electron temperature between hydrogen plasmas and helium plasmas, the ion central temperature measured by a crystal spectrometer was clearly higher for helium plasmas than for hydrogen plasmas where  $n_{e,\text{avg}} \sim 0.5 \times 10^{19} \text{ m}^{-3}$ . ECRH was modulated to evaluate ECRH power deposition for the transport analysis in some experiments. The ECRH total power and deposition profiles were evaluated from the electron temperature, electron density and the

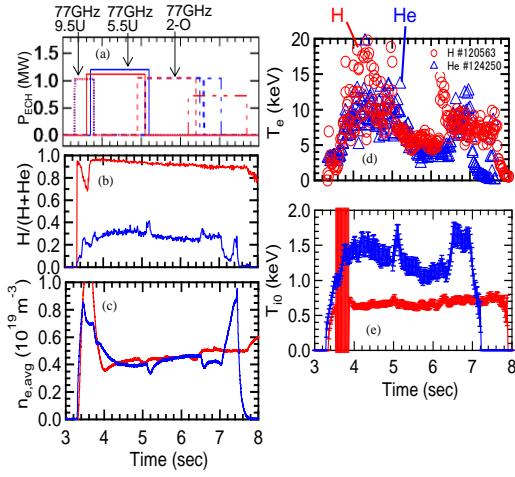


Fig.1 Temporal evolution of (a) ECRH injection power, (b) ratio of hydrogen to helium, (c) line averaged electron density, (d), (e) electron and ion temperature in hydrogen (red) and helium plasmas (blue).

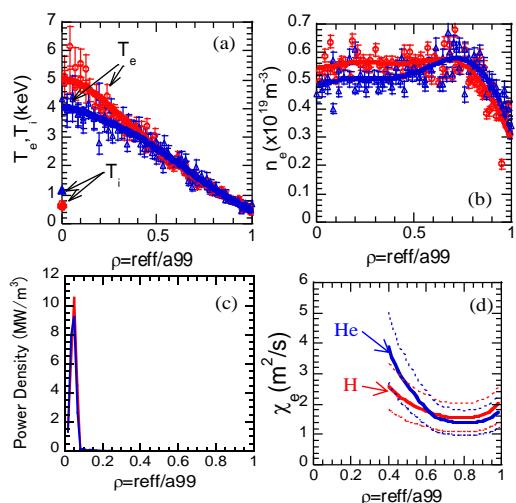


Fig.2 Profiles of (a) electron and ion temperature, (b) electron density, (c) ECRH absorbed power density, (d) electron thermal diffusion coefficients of hydrogen and helium plasmas. Dash lines in (d) show the error caused by ECRH power evaluation.

diamagnetic stored energy experimentally [3], and calculated by ray trace code LHDGauss [4]. The deposition profile evaluated experimentally is broader than simulation result because experimental evaluation includes transport effects, however, the experimental estimation of the total power is good estimation. The profiles of ECRH deposition by LHDGauss were calibrated by the experimentally evaluated values of the total power. The power balance analysis was performed using TASK3D [5] with estimated ECRH power deposition to evaluate the electron heat diffusion coefficients. We assumed that H ratio is 100 % for “hydrogen plasmas” and He ratio is 100% for “helium plasmas” in the power balance analysis using TASK3D. Figure 2 shows comparison of the profiles of the electron and ion temperature, the electron density, the electron thermal diffusion coefficients of hydrogen and helium plasmas where  $n_{e,avg} \sim 0.5 \times 10^{19} \text{ m}^{-3}$ . The ion temperature profile was assumed parabolic distribution with the central ion temperature for TASK3D. The evaluation of the electron heat diffusivity is valid at only  $\rho > 0.4$  because the EC heating position estimated

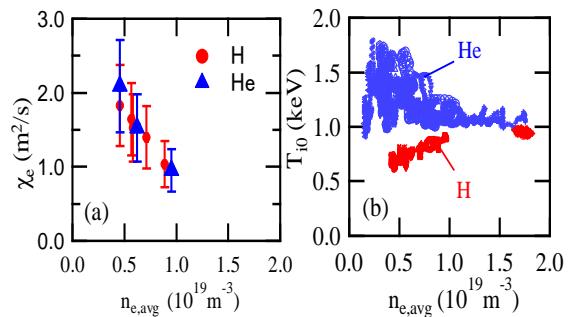


Fig.3 Comparison of (a) electron heat diffusion coefficient at  $\rho \sim 0.6$  and (b) central ion temperature related to the line averaged electron density in hydrogen (red) and helium plasmas (blue). The error bar in (a) shows the error caused by ECRH power evaluation.

from the electron temperature measured by the electron cyclotron emission systems was  $\rho < 0.4$ . There is no difference in the electron heat diffusivity at  $\rho > 0.4$  for hydrogen and helium ECRH plasmas. In edge region, the error of the electron heat diffusivity become larger due to the increase in the volume-integrated power transferred from electron to ion  $P_{ei}$  because  $P_{ei}$  depends on assumption of ion temperature profile. Therefore, analysis of the electron heat diffusivity focuses on at  $\rho \sim 0.6$ . Figure 3 shows density dependence of electron heat diffusivity at  $\rho \sim 0.6$  and the central ion temperature. There is no difference in the electron heat diffusivity in hydrogen and helium ECRH plasmas. The central ion temperature is higher in helium plasmas than in hydrogen plasmas in low electron density region  $n_{e,\text{avg}} < 1.2 \times 10^{19} \text{ m}^{-3}$ . There is little difference in higher electron density  $n_{e,\text{avg}} > 1.2 \times 10^{19} \text{ m}^{-3}$ . The difference in the central ion temperature may indicate the ion heat diffusivity is larger for hydrogen than for helium plasmas in low density region.

### 3. Comparison of Particle Transport

The particle transport in hydrogen and helium plasmas was investigated by density modulation experiments, as shown in Fig. 4. NBI was injected till 2.5 sec in hydrogen plasmas, and hydrogen plasmas were sustained by 77 GHz and 154 GHz ECRH. Helium plasmas were sustained by only 77 GHz and 154 GHz. ECRH power was 0.9 MW in total for both hydrogen and helium plasmas. Density was modulated at 1.25Hz. In ECRH sustainment phase, the line averaged electron density was kept almost constant in hydrogen plasma, while it increases in time in helium plasma due to the high recycling rate of helium. The particle transport was compared in L mode phase after back transition from e-ITB. Ionization rate was estimated by 3D Monte Carlo simulation code EIRINE [6]. Figure 5 shows comparison of the profiles of the electron temperature, density and ionization rate averaged at 6-6.8 sec. The electron density profile is flat in hydrogen plasmas and hollow in helium plasmas. Particle source penetrates deeper toward core in hydrogen plasma because hydrogen atoms

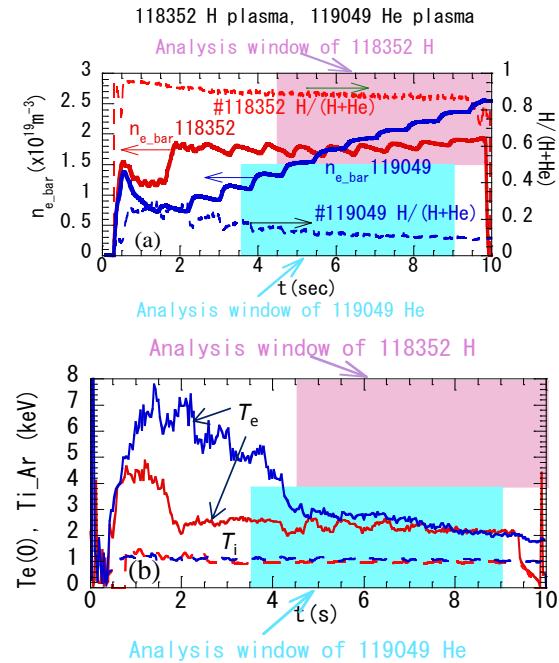


Fig.4 Temporal evolution of (a) line averaged electron density and ratio of hydrogen to helium, (b) central electron and ion temperature in hydrogen and helium plasmas.

penetrate deeper by the charge exchange with high temperature hydrogen ions. Diffusion coefficient  $D$  and convection velocity  $V$  are evaluated taking into account of difference of ionization rate. The diffusion coefficient and convection velocity are determined to fit both equilibrium profile and modulation profile [7]. Figure 6 shows the diffusion coefficients and convection velocity. Diffusion coefficient in helium plasma is higher than in hydrogen plasma, in edge region. The convection velocity is outwardly in core region in helium plasmas, while close to zero in hydrogen plasmas. In edge region, higher inwardly convection velocity is observed in helium plasmas. The total particle transport is dominated by diffusive flux in the edge region. The particle transport is larger for helium plasmas than for hydrogen plasmas in edge region due to larger diffusion coefficients.

#### 4. Summary

The properties of heat and particle transport of hydrogen and helium ECRH plasmas were compared on LHD. There is no difference in the electron heat diffusivity at  $\rho > 0.4$  for hydrogen and helium ECRH plasmas. The central ion temperature measured by a crystal spectrometer was higher for helium plasmas than for hydrogen where  $n_{e,\text{avg}} < 1.2 \times 10^{19} \text{ m}^{-3}$ , while there is little difference where  $n_{e,\text{avg}} > 1.2 \times 10^{19} \text{ m}^{-3}$ . The particle transport is larger for helium plasmas than for hydrogen in edge region due to larger diffusion coefficient.

#### References

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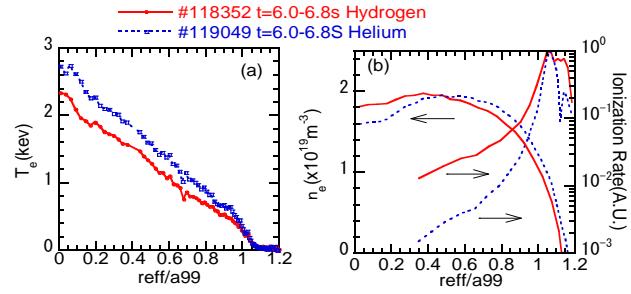


Fig.5 Profiles of (a) electron temperature, (b) electron density and ionization rate.

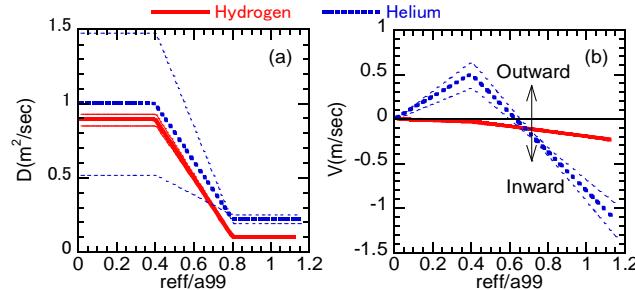


Fig.6 Comparison of (a) diffusion coefficient, (b) convection velocity in hydrogen and helium plasmas.