18PB-079

The Influence of Proton Impact Excitation on the Hydrogen Balmer-α Line Spectrum in LHD Plasmas

LHDプラズマの水素バルマーα線スペクトルに見られる陽子衝突励起の影響

Yuta Nakai[1)], Keisuke Fujii[1)], Motoshi Goto[2)], Shigeru Morita[2)], and Masahiro Hasuo[1)]

中井悠太[1)]，藤井恵介[1)]，後藤基志[2)]，森田繁[2)]，蓮尾昌裕[1)]

[1)] Graduate School of Engineering, Kyoto University, Kyoto 615-8540, Japan

京大工　〒615-8540　京都市西京区京都大学桂

[2)] National Institute for Fusion Science, 322-6 Oroshi-cho, Toki 509-5292, Japan

核融合研　〒509-5292　土岐市下石町

We observe the Balmer-α emission from LHD plasmas with T_i^{core} = 2 keV and 8 keV, where T_i^{core} is the core ion temperature, with the high dynamic range spectrometer. We simulate the hydrogen atom transport from the edge to core regions taking the rates of electron and proton collisions into account. By comparing the observed and simulated spectra, we find that the effect of the proton impact is negligible for the T_i^{core} = 2 keV plasma, while the proton impact excitation is dominant in the far wing region of the spectrum for the T_i^{core} = 8 keV plasma. This means that we need to consider the proton impact excitation process in the n_H evaluation method based on the spectral analysis for high ion temperature plasmas.

1. Introduction

In magnetically confined fusion devices, most of hydrogen atoms are ionized in the edge region of the plasma. However, some atoms are heated by charge-exchange collisions with hot protons and penetrate into the core region [1]. Information about the atom transport in the core region is demanded because it affects the particle and energy balances of the plasma.

Recently, we have found that the emission from the hydrogen atoms in the core region of an LHD plasma having the core ion temperature, T_i^{core}, of 2 keV can be detected as the far wings of the observed Balmer-α line profile [1,2]. We have also proposed a method to evaluate the atom density distribution in the confined region based on the profile analysis assuming only electron impact excitations to the n = 3 state, where n is the principal quantum number [1].

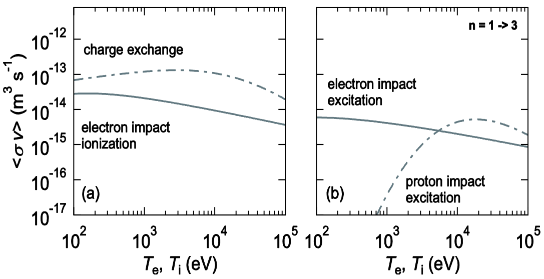

Fig.1: Rate coefficients of (a) the charge exchange and electron impact ionization and (b) the electron and proton impact excitations [3-5].

Figure 1(a) and (b) show the rate coefficients of the electron impact ionization and excitation to the n = 3 state of hydrogen atom, respectively, against electron temperature T_e together with those of proton impact against ion temperature, T_i. It is seen in (b) that the coefficient of the proton impact excitation becomes larger than that of the electron excitation when the temperature exceeds 5 keV. In this work, we investigate this effect on the Balmer-α emission spectrum.

2. High dynamic range Balmer-α spectra

Figure 2 shows the radial distributions of T_i, T_e and electron density, n_e of the T_i^{core} = 2 keV (#121292) and T_i^{core} = 8 keV (#119128) plasmas generated in

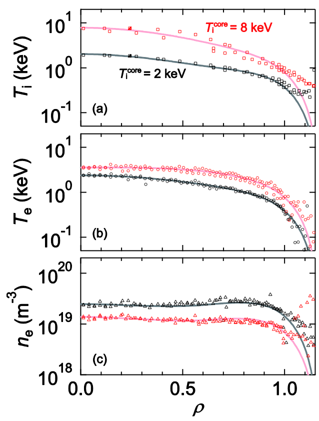

Fig.2: The radial distributions of (a) T_i, (b) T_e and (c) n_e of the T_i^{core} = 2 keV and 8 keV plasmas

the LHD. The dots in Figs. 3(a) and (b) show the Balmer-α line profiles observed for these plasmas with the high dynamic range spectrometer, which we developed previously [6]. In the figure, the intensity is plotted with a logarithmic scale. The slope of the wings observed for the T_i^{core} = 8 keV

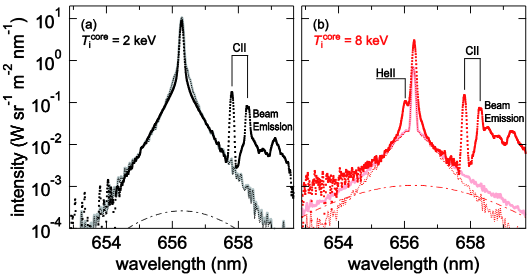

Fig.3: The observed and simulated spectra of the (a) T_i^{core} = 2 keV and (b) T_i^{core} = 8 keV plasmas

plasma is smaller than that for the T_i^{core} = 2 keV plasma.

3. Monte-Carlo simulation of the atom transport

We simulate trajectories of hydrogen atoms in the three-dimensional space from the outermost region of these plasmas to the ionization point repeatedly using a Monte-Carlo method. In the simulation, we assume that the velocities of the colliding atom and proton are exchanged at the charge-exchange collision. The radial distributions of the charge-exchange and ionization collision rates are calculated from their rate coefficients (Fig.1 (a)) with the measured radial distributions of T_i, T_e and n_e (Fig.2). Since the measured values of T_i, T_e and n_e are unavailable in the outermost region of the plasma, we use the extracted values with polynomial functions. We assume $n_e = n_p$, where n_p is the proton density. After tracing many atom trajectories, the radial density distribution of the ground state atoms with their velocity distribution at every radial position is statistically evaluated. The evaluated radial density distributions are shown in Fig.4. We note that this model simulates only the relative values of the density not the absolute one. For the calibration, we scale the results so that the simulated relative spectra described later to fit the observed ones.

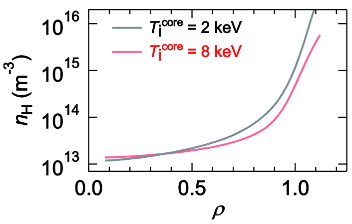

Fig. 4: Calculated density distributions of the ground state hydrogen atoms.

From the evaluated density distributions with the excitation rate coefficients shown in Fig.1 (b), we calculate the radial density distributions of the n = 3 state atoms excited by the electron and proton impacts as shown in Fig.5.

The electron impact excitation is the dominant in both the edge and core regions of the T_i^{core} = 2 keV plasma, while the proton impact excitation is dominant in the core region of the T_i^{core} = 8 keV plasma.

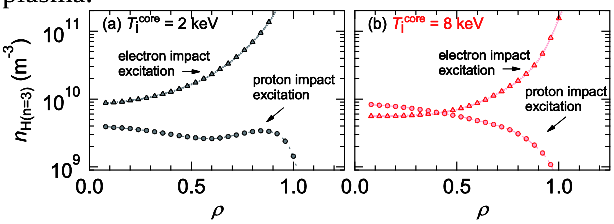

Fig. 5: The radial density distributions of the n = 3 state hydrogen atoms in the (a) T_i^{core} = 2 keV and (b) T_i^{core} = 8 keV plasmas

4. Comparison between the observed and simulated spectra

From the calculated density and velocity distributions of the n = 3 atoms, we construct the Balmer-α spectral profiles for the T_i^{core} = 2 keV and T_i^{core} = 8 keV plasmas, taking the Doppler effect and the emission integration along the line of sight into account. The results are shown by solid curves in Fig.3 (a) and (b), respectively. The simulated results well reproduce the observed ones especially in the wing regions. We note that the discrepancy around the spectral center, which is probably due to the inappropriate values of T_i, T_e and n_e in the outermost region used in this model, have little impact on the calculated result of the atom density in the core region and wing shapes.

By the dotted and dashed curves in the figure, we show the spectral components which originate from the collisional excitation by electrons and protons, respectively. For the T_i^{core} = 2 keV plasma, the electron impact excitation is dominant in both the center and wing regions of the spectrum, i.e. the effect of the proton impact can be neglected. On the other hand, for the T_i^{core} = 8 keV plasma, the proton impact excitation is dominant in the far wing region. This result indicates that the proton impact excitation process should be taken into account in the n_H evaluation method based on the spectral analysis for high ion temperature plasmas.

References

[1] M. Goto, K. Sawada, K. Fujii et al., Nucl. Fusion, **51** 023005 (2011)

[2] K. Fujii, T. Shikama, M. Goto et al., Phys. Plasmas **20**, 012514 (2013)

[3] P.S. Krstic and D.R. Schultz, J. Phys. B **36**, 385 (2003)

[4] R.K. Janev and J.J. Smith, *ATOMIC AND PLASMA-MATERIAL INTERACTION DATA FOR FUSION VOLUME 4*, IAEA, 1993

[5] V. Shevelko, D. Kato, M.Y. Song et al., Nucl. Instrum. Methods B **267**, 3395 (2009).

[6] K. Fujii, S. Atsumi, S. Watanabe et al., Rev. Sci. Instrum. **85**, 023502 (2014)