§12. Evaluation of Neutral Atom Density in the Plasma Core Region Based on the Balmer-α Line Profile

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The central region of a poloidal plasma cross section horizontally elongated was viewed with a single line-of-sight. The measurement was made for a discharge (#93539) with $R_{ax} = 3.65$ m and $B_{ax} = 2.712$ T, where R_{ax} and B_{ax} are the major radius of the magnetic axis and the magnetic field strength at the magnetic axis, respectively. We assume that the observed line profile $I(\lambda)$, where λ is the wavelength, is expressed as

$$I(\lambda) = \int_0^\infty f(w)\frac{1}{\sqrt{\pi}w}\exp\left[-\left(\frac{\lambda-\lambda_0}{w}\right)^2\right]dw. \qquad (1)$$

Here, λ_0 and w are the wavelength at the line center and the Gaussian half width, respectively, and $f(w)$ is the contribution fraction of a Gaussian component having the width of w to the entire line profile. After replacement of variables as $s = (\lambda-\lambda_0)^2$ and $t = 1/w^2$, Eq. (1) can be rewritten in the form of Laplace transform as

$$\mathscr{F}(s) = \int_0^\infty F(t)\exp(-st)\,dt, \qquad (2)$$

with $F(t) = f(t^{-1/2})/(2\sqrt{\pi}t)$. The kernel $F(t)$ is determined as a result of numerical inversion of Eq. (2). The distribution function $f(w)$ is readily obtained from $F(t)$ and it can be further interpreted as a function of atom temperature T_a as $g(T_a) = f(w)dw/dT_a$, where $w = \lambda_0(2kT_a/(Mc^2))^{1/2}$, and M, c, and k are the atom mass, light speed, and Boltzmann constant, respectively.

Under the assumption of $T_a = T_i$ at the same location, the distribution function $g(T_a)$ obtained above also indicates the spatial distribution of the line emissivity because T_i is different at different location. Since the condition of $T_i = T_e$, where T_e is the electron temperature, is approximately established in the present plasma, the T_e profile obtained with the Thomson scattering measurement can be used to correlate the temperature dependence with the spatial dependence. Since the T_e profile is single-peaked at the magnetic axis, there exist two locations on the line-of-sight which are assigned to the same T_e. The function $g(T_a)$ is thus regarded as the sum of contributions from those two locations. Here, we consider their average and derive the radial profile of the emissivity η, as

$$\eta(R) = g(T_a)\bigg/\left(\left|\frac{dR}{dT_e}\right|_{in} + \left|\frac{dR}{dT_e}\right|_{out}\right), \qquad (3)$$

where R is the major radius and the derivatives $|dR/dT_e|_{in}$ and $|dR/dT_e|_{out}$ are those at the locations assigned to the same T_e in the regions inboard-side and outboard-side of the magnetic axis, respectively.

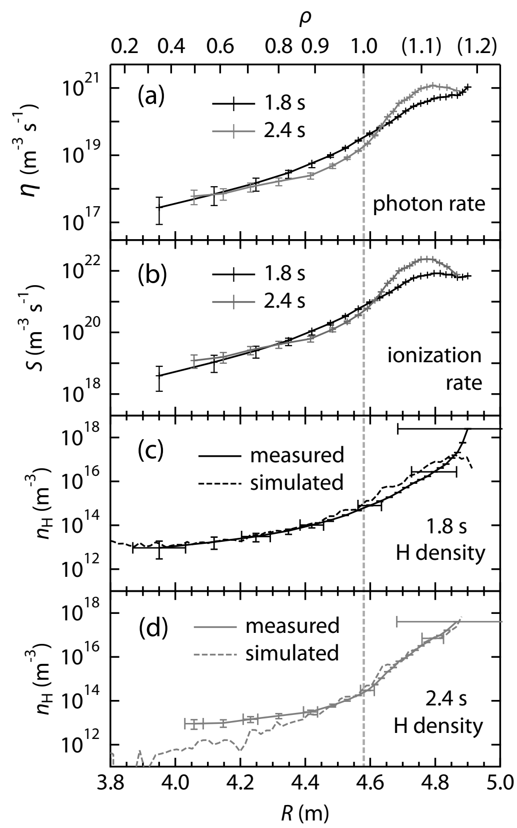

Fig. 1: Radial distribution of photon emission rate (a), ionization rate (b), and atom density (c, d) in the outboard-side region. The thin lines in (c) and (d) are the results of Monte-Carlo simulation.

The radial emissivity profiles $\eta(R)$ at two different periods of time in the discharge are shown in Fig. 1 (a) with the black and grey lines, respectively. Here, only the outboard-side region is shown. The ionization rate S and atom density n_H are evaluated from η and the T_e and n_e profiles with a help of the collisional-radiative model. Figure 1 (b) shows S and Fig. 1 (c) and (d) shows n_H. The horizontal error bars are evaluated from the mean free path of the created atoms due to momentum transfer elastic collisions.

We have also developed a three-dimensional Monte-Carlo simulation code for examining the results obtained. The code traces the neutral particles introduced in the vacuum vessel until they are finally ionized. Recycled hydrogen molecules from the divertor plates are considered as the test particles. The code handles atomic and molecular excited levels as well as the ground state individually and careful attention has been in particular paid for incorporation of molecular processes. The n_H profiles obtained are shown with the dashed lines in Fig. 1 (c) and (d). The results are normalized so that the integrated photon emission rate has the same magnitude as the experimental result. General consistency regarding the decay length of the atom density is obtained with the experimental result in the both periods of time so that the validity of the present methodology is corroborated.