JP0055454

Apparent Wavelength Shifts of H-like Ions Caused by the Spectral Fine Structure Observed in CHS Plasmas

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Abstract. The effect of the spectral fine structure of H-like ions on the plasma rotation measurements was investigated using the 'bidirectional' viewing of the charge exchange excited CVI lines. The wavelength given by a single Gaussian fitting shows the apparent wavelength shifts of $\Delta\lambda$ ~0.01 Å depending the ion temperatures in the range of ~100eV.

1 Introduction

The spectroscopic measurements of plasma rotations are widely used to measure radial electric fields in magnetically confined plasmas. For the precise measurement of Doppler shifts in the rotation velocity range of a few km/s[1,2], there are several problems that come from the mechanical wavelength offset in spectrometers and so on. The best approach to measure the absolute value of Doppler shifts canceling the wavelength offset is the bidirectional viewing (simultaneous two viewing along opposite viewing directions)[3]. The results of charge exchange spectroscopy(CXS)[4] using this method in the Compact Helical System(CHS) clarified another problem which comes from the spectral fine structure of hydrogen-like ions.

In this paper, the observed effect of the fine structure on the plasma rotation measurements is presented. CHS is a Heliotron/Torsatron type helical torus with the major radius of R=1m, the averaged minor radius of a=0.2m and the magnetic field strength of <2T. Charge exchange excited spectral lines from the heating neutral beam (<40kV, <1MW) are used for the spectroscopic measurements of the ion temperature and the poloidal rotation. The measurement system has two fiber arrays viewing the plasma from upper and lower ports simultaneously at the vertically elongated section (port 7D and 7U), and the average of the wavelength measured from both sides gives the wavelength without Doppler shifts ($\Delta\lambda$ = 0). And it uses one more fiber array to measure the background radiation at another vertically elongated section (port 8D). All of these fibers (90ch) are connected to the entrance slit of a spectrometer and the diffraction image is detected by a CCD camera with an image intensifier.

2 Results and Discussions

The hydrogen-like ions created by the charge exchange reaction of the beam neutrals and the fully ionized plasma ions have the splitting of energy levels due to a relativistic effect expressed in the formula

$$E(n,j) = -\frac{Z^2 R_y}{n^2}\left[1+\frac{(\alpha Z)^2}{n}\left(\frac{1}{j+1/2}-\frac{3}{4n}\right)\right]$$

where, n is principal quantum number, j is total angular momentum, Z is nuclear charge, R_y is Rydberg constant and α is fine structure constant (=1/137). The sub-level populations that determine the intensity ratio of fine structure components can be assumed to be proportional to statistical weights $2(2l+1)/n^2$ based the collisional l-mixing model[4]. Figure 1 shows the example of observed spectral profiles of the CVI line(Δn=7-6, λ =3434Å) and the fine structure pattern calculated with this assumption. The fitting with the super-position of fine structural components with Doppler broadening shows better agreement with the measured

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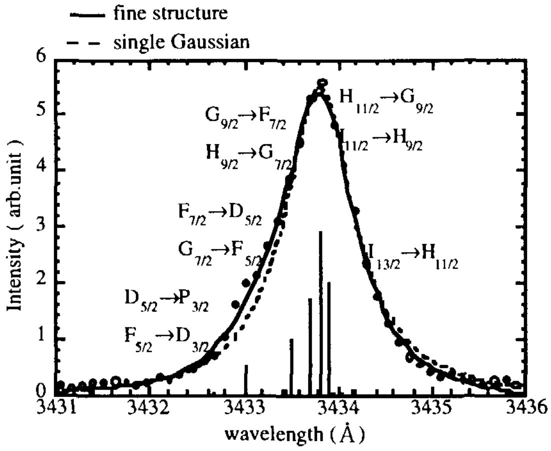

Figure 1:Spectral profile of the CVI line(Δn=7-6).

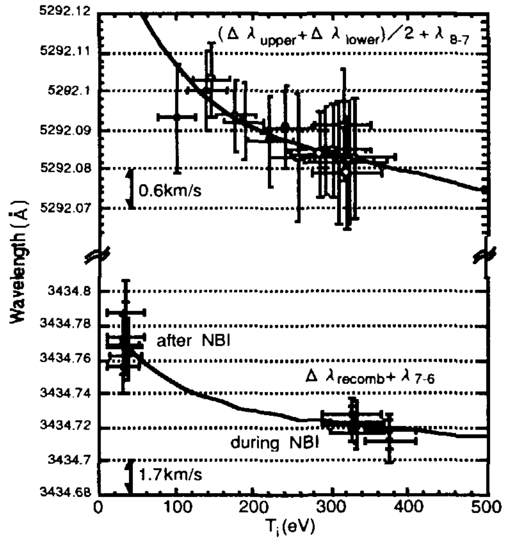

Figure 2: Apparent wavelength.

spectrum than the fitting with single Gaussian profile. The red-side/blue-side asymmetry of the spectral pattern causes the ion temperature (i.e. Doppler width) dependence of the the center wavelength for the half-maximum of spectral profiles. The solid curves in Figure 2 show the center wavelength for the half-maximum of calculated spectral profiles. They shifts to the red side with decreasing ion temperature and total shift in the ion temperature range of hundreds eV corresponds to the velocity error of a few km/s.

The wavelength shifts given by a least square fitting of single Gaussian profile to the measured Doppler broadened CVI spectral lines in visible range(Δn=8-7, λ =5290 Å and Δn=7-6, λ =3434 Å) show apparent shifts, not due to the real Doppler shifts, depending on the ion temperatures. These apparent shifts can be distinguished from the real Doppler shifts by the bidirectional viewing. The Δn=8-7 line observed in the plasma having the center ion temperature of $T_i(0)$=330eV shows red-side shifts in the peripheral region with the ion temperature of $T_i(r\sim a)$=100eV. The wavelength of the line without the Doppler shift is given by the 'average' of the measured 'wavelength' at the upper and lower viewing ports ($(\Delta\lambda_{upper} + \Delta\lambda_{lower})/2 + \lambda_{8\text{-}7}$, where $\lambda_{8\text{-}7}$ is taken to be 5292.082 Å. The Δn=7-6 line observed in the after-glow phase of NBI heated plasma also shifts to red-side compared to the NBI heated phase. The wavelength of this line is given by $\Delta\lambda_{recomb} + \lambda_{7\text{-}6}$, where $\Delta\lambda_{recomb}$ is the wavelength jump from the NBI phase to the after-glow recombining phase and $\lambda_{7\text{-}6}$ is taken to be 3434.72 Å. Open circles in Figure 2 show these measured wavelength. The observed dependence on the ion temperature can be explained by the prediction from the fine structure calculation.

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