§85. Energy Dependence of Emission Cross Sections for Charge Exchange Recombination Process

Murakami, I., Ida, K., Yoshinuma, M., Nagaoka, K., Kato, D., Kamiya, K. (JAEA)

Charge-exchange spectroscopy (CXS) is a method measuring visible emission line emitted from an impurity ion which captures an electron from neutral hydrogen of a neutral beam. A charge exchange (CX) collision process of a naked impurity ion, such as C^{6+}, and a neutral hydrogen produces a hydrogen-like impurity ion, such as C^{5+}, in highly excited state n, which emits a visible emission line, such as C VI λ = 529.09nm line of n = 8-7 transition:

$$C^{6+} + H^0 \rightarrow C^{5+}(n=8) + H^+$$
$$\rightarrow C^{5+}(n'=7) + h\nu\ (\lambda=520.09\text{nm})$$

A Doppler shift and a Doppler width of such an emission line give us information of ion temperature and rotation velocity of plasma at a position where a neutral beam and a sight-line cross. The emission intensity is proportional to the neutral H density, the impurity ion density, the CX cross section σ^{CX}, and the relative velocity of the impurity ion and neutral hydrogen, $|\Delta v|$. Because the charge exchange cross section depends on collision energy, i.e., the relative velocity of the impurity ion and neutral hydrogen, ion thermal motion causes apparent additional velocity[1] and emission cross section $<\sigma^{CX} |\Delta v|>$ becomes different when the direction of the ion motion is the same as or opposite to the direction of the neutral beam. If the beam energy is smaller than the collision energy of the maximum CX cross section, the emission cross section for ions moving opposite to the beam direction becomes larger than the one for ions moving to the same direction of the beam. This causes an apparent Doppler shift with opposite direction to the beam. This apparent Doppler shift is proportional to the ion thermal temperature.

There are several theoretical methods to calculate CX cross sections for different energy ranges. There also have been many efforts to obtain scaling law or empirical formulae for CX cross sections by comparing with experimentally obtained total CX cross sections or state-selective cross sections for lower excited states. There are no measurements of state-selective cross section for high excited states, such as n=8 for C^{5+} and the analysis of CXS relies on theoretically obtained cross sections. The CX cross sections are different among ones obtained by different authors.

We have tried to measure the energy dependence of the emission cross sections of the C VI n=8-7 transition caused by the CX process of the impurity C^{6+} ion and neutral hydrogen of the neutral beam for LHD plasmas. We measured the apparent Doppler shift and ion temperature for plasma center with varying beam energy of the LHD #4 NBI system from 25 to 40kV, and obtained the averaged ratio of apparent Doppler shift to ion temperature.

Measured ratio is compared with theoretically calculated ratio (Fig.1). We use ADAS[2] to calculate the emission cross section with the CX cross section data set named "qcx#h0_old#c6.dat". This data set is obtained as a preferred data set by combining with several data. We considered the contribution of E/2 and E/3 components to the emission cross sections for theoretical ratio, where E is beam energy.

As shown in Fig.1, measured ratio agrees only at E~35keV with the theoretical prediction (solid line), and energy dependence is much weaker than the theoretical prediction. This difference implies that the emission cross section peak would be shifted to higher energy than 50keV and the energy dependence of the CX cross section would be less steep than one of ADAS for this energy range.

There is a suggestion to include corrections due to contamination of metastable hydrogen in neutral beam for analysis of rotation velocity by CXS[3]. If neutral beam has 0.3% population of hydrogen in metastable state (n=2), the emission cross section is enhanced at low collision energy and the measurements of ion velocity in DIII-D could be reproduced. If we include this contribution from metastable hydrogen to the emission cross section similarly, the ratio of apparent velocity to ion temperature becomes much smaller than our measurements (dashed line in Fig.1). This contribution cannot explain large ratio at 40keV, either.

We will examine the CX cross sections in more detail for further analysis.

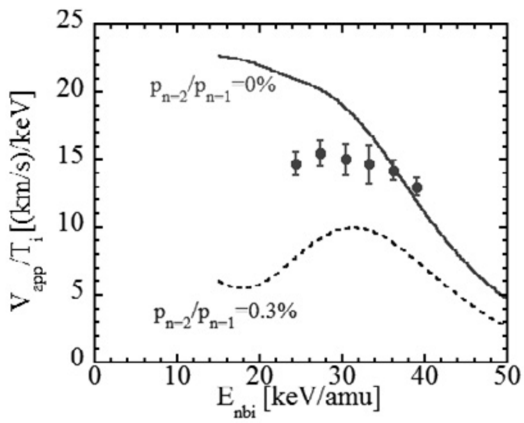

Fig. 1. Energy dependence of the ratio of apparent velocity to ion temperature for experiments (solid circle) and theoretical predictions for no metastable state case (solid line) and 0.3% metastabe state case (dashed line).

1) Yoshinuma, M. et al.: Fusion Sci. Tech. **58** (2010) 375.
2) Summers, H. P.: The ADAS User Manual ver. 2.6 (2004), http://www.adas.ac.uk/.
3) Solomon, W. et al.: Phys,. Plasmas **13** (2006) 056116.