§6. Study on Various Atomic Processes of Impurity Highly Charged Ions by Versatile Ion Sources

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Atomic processes of impurity ions of heavy elements in magnetically confined fusion plasmas have been issues of study concerning plasma radiation cooling, precise measurements of ion temperature and local magnetic field at core plasmas, secondary-particle emission in plasma-wall interaction, and so on. Our research aims at collecting and evaluating relevant atomic data of highly-charged ions of heavy elements. To this end, we promote a cooperative research at a high performance electron-beam-ion-trap (Tokyo-EBIT) of ILS (UEC) and an electron-beam-ion-source (NICE) of NIFS.

In 2005, we participated with measurements of dielectronic recombination (DR) at Tokyo-EBIT. In DR, an incident electron pushes electrons of a target ion up to excited levels, and is trapped by the target ion. The intermediate excited-state is unstable. It decays by releasing electrons, or is relaxed by emitting photons. DR is the latter case, and it becomes more probable for ions of higher charge-states. DR is therefore the most important radiation energy-loss process of high-temperature plasmas containing heavy impurity elements. At UEC, an experimental method was devised to measure total DR cross sections for ions of a certain charge-number. At ionization equilibrium of EBIT, number densities of ions (n) are determined by cross sections (σ) of electron-impact ionization (EI), radiative recombination (RR), DR and charge-exchange (CX) with surrounding neutral gas particles. Assuming the coronal model, ratio of the ion number densities of neighboring charge state q and $q-1$ is written as,

$$\frac{n_{q-1}}{n_q} = \frac{\sigma_q^{DR} + \sigma_q^{RR} + \langle \sigma_q^{CX} \rangle}{\sigma_{q-1}^{EI}} \quad (1),$$

where $\langle \ \rangle$ stands for effective values at certain electron-beam currents. DR cross section would have peaks at certain incident electron energies which coincide with resonance energies of the intermediate excited states. Apart from the resonance energies, the cross section values would be zero. The other cross sections have smooth variation over electron-beam energies. Thus, DR cross sections can be isolated by subtracting rapidly varied component of the number density ratio from smooth component. The number density ratios of certain charge-states were obtained by measuring extracted ion intensities from EBIT using a position-sensitive detector placed after a charge-analyzing magnet.

At Tokyo-EBIT, the above method was used successfully to measure KLL-DR cross sections of He-like though B-like Bi ions. We are preparing the similar experiments at NICE in order to measure DR cross sections of Fe ions. Concentration of Fe ions and their radiation power at the core plasma of LHD have been issues of study. We will measure hitherto unknown chare-state specific DR cross sections of Fe ions to have an insight into mechanisms of radiation collapse and density limit of LHD plasma containing Fe ions. Also, the cross section data of Fe ions may be important for diagnostics of non-equilibrium high-temperature plasmas at the solar corona; our measurements will serve for precise EUV spectroscopy by the Solar-B satellite which will be launched in 2006.