§13. Identification of Resonance Excitation Double-Autoionization of Li-like Iodine Ions

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Electron-impact ionization of highly-charged ions is important to understand energy balance and ionization balance of non-equilibrium high-temperature plasmas. Total ionization cross sections are substantially increased by the resonance excitation double-autoionization (REDA). In REDA, an incident electron pushes electrons of a target ion up to excited levels, and is trapped temporary by the target ion. The electron attached (excited) state is relaxed by releasing two electrons via two sequential autoionizations. As a result, the target ion loses one electron. The REDA cross section would have peaks at certain incident electron energies which coincide with resonance energies of the electron attached states. Apart from the resonance energies, the cross section values would be zero.

We identified the REDA peak of Li-like iodine ions by analyzing ion density ratios of He-like and Li-like ions in an electron beam ion trap (EBIT) [1]. Ionization equilibrium in the EBIT is determined by balance among rates of electron-impact ionization which includes direct ionization (DI), excitation autoionization (EA) and REDA, recombination which includes radiative recombination (RR) and dielectronic recombination (DR), and ion loss due to ion escape from the trap or charge exchange with neutral particles. Denoting the DI+EA cross section by σ^{DI+EA} [cm^2], the REDA cross section by σ^{REDA}, the RR+DR cross section by σ^{RR+DR} and the ion loss rate by $1/\tau$ [s^{-1}], ratios of the He-like ion density, n_{He}, to the Li-like ion density, n_{Li}, are written for a given electron beam current density, j [cm^{-2}s^{-1}], as,

$$\frac{n_{\rm He}}{n_{\rm Li}} = \frac{\sigma_{\rm Li}^{\rm DI+EA} + \sigma_{\rm Li}^{\rm REDA}}{1/j\tau + \sigma_{\rm He}^{\rm RR+DR}} \qquad (1),$$

provided the electron beam energy is lower than the ionization energy of the He-like ion. To obtain eq. (1), the coronal model is assumed since the electron density is as low as 10^{-12} cm^{-3} in the EBIT. In conjunction with ion density ratios at off resonance energies, $(n_{He}/n_{Li})_{NR}$, the REDA cross sections are written as,

$$\sigma_{Li}^{REDA} = \sigma_{Li}^{DI+EA}\left[\frac{(n_{He}/n_{Li})}{(n_{He}/n_{Li})_{NR}} - 1\right] \qquad (2).$$

Extracted ion intensities from the EBIT were measured by a position-sensitive detector placed after a charge-analyzing magnet. Figure 1 shows the REDA cross section determined by eq. (2) with the measured ion intensity ratios and theoretical values of σ^{DI+EA}. Theoretical REDA cross section curve is also plotted for comparison. As seen in Fig. 1, the REDA peak is identified as composition of three electron attached states: $(1s2s3s^2)_{J=1}$ and $(1s2s3s3p)_{J=0,1}$.

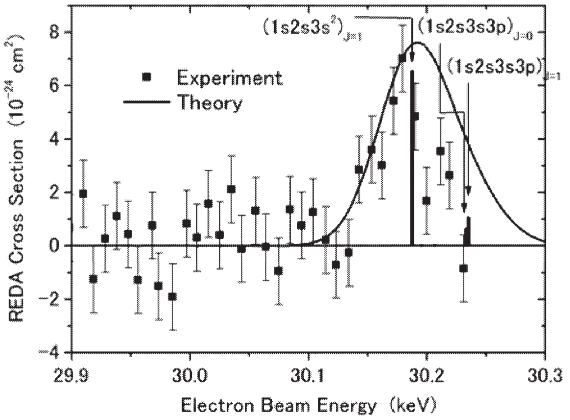

Fig. 1 Measured and theoretical REDA cross sections. The theoretical cross section is convoluted by a Gaussian function with electron energy width of 70 eV.

References

1) Nakamura, N., Tobiyama, H., Nohara, H., Kato, D., Watanabe, H., Currell, F.J. and Ohtani, S., Phys. Rev. A 74 (2006) 020705(R).