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Electron impact ionization of ground-state Be-like rare gas ions

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Abstract. Detailed calculations for electron impact ionization including direct ionization (DI) and excitation autoionization (EA) processes along the ground-state Be-like rare gas ions have been performed by using relativistic distorted wave (RDW) approximation. The DI contribution from 2s shell and the EA contributions from inner-shell electron impact excitations of $1s-nl$ ($n\leq 12$, $l\leq 4$) were considered. The contribution of DI is a little more than 90% to the total electron impact ionization cross section. The main EA contribution comes from $1s-2p$ electron impact excitation channel. The EA contribution relative to DI contribution first increased and then decreased as the atomic number Z increases in Be-like rare gas ion. The EA rate coefficients are given for all ground-state Be-like rare gas ions as a function of impact electron temperature.

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Key words: electron impact ionization, excitation autoionization (EA), relativistic distorted wave (RDW) approximation

1 Introduction

Rare gas ions are frequently introduced in tokamaks as density diagnostic elements for probing fusion plasmas. For this reason, a good knowledge of related spectroscopic and collisional atomic data is needed in order to interpret the observation of various plasma parameters. Among the processes playing a role in this field, electron impact ionization of atoms or ions is a fundamental one, because it governs the ion charge state distribution evolution in the plasma so that the corresponding ionization cross sections and rate coefficients are required for plasma modeling [1]. The indirect electron impact ionization processes such as excitation autoionization (EA), which consists of collisional excitation

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to a level above the ionization limit followed by autoionization, can dominate the total impact ionization cross section for many ions at energies above the threshold. Recently much attention has been paid to the electron impact ionization processes of ground-state Be-like rare gas ions, and the importance of EA process for Be-like rare gas ions has been shown in experimental measurements of total ionization cross sections and theoretical investigations [2-6]. Duponchelle *et al.* have clearly found the K-L excitation autoionization for Ne^{6+} contributes for some 7% of the total cross section at the corresponding threshold (888.3 eV) using animated crossed-beams method [2]. In previous theoretical researches [3, 5], the EA contributions of Ne^{6+} and Ar^{14+} have been shown clearly. However, no systematic analysis for the contributions of excitation to autoionizing intermediate states of Be-like rare gas ions was available prior to the present work. The above discussions motivate us to investigate the impact ionization including the direct ionization (DI) from $2s$ shell and EA contribution from all electron impact excitations of $1s-nl$ ($n \leq 12$, $l \leq 4$) for ground-state Be-like rare gas ions.

The remainder of the paper is arranged as follows. In Section 2 we give a brief outline of the theoretical method. In Section 3 the results of our calculations are presented and discussed. Finally a brief summary is contained in Section 4.

2 Theoretical method

In the present work, we consider the DI process of ground-state Be-like rare gas ions from $2s$ shell,

$$1s^2 2s^2 + e \rightarrow 1s^2 2s + 2e. \tag{1}$$

The direct ionization from $1s$ shell is not included in our calculations, for the direct ionization of the $1s$ electron in fact lead to a double ionization of Be-like ion [7]. The direct ionization (DI) cross sections are calculated by using the RDW approach implemented in the computer package FAC, which has been widely used to study the DI process [8, 9].

The EA from the ground level $g(1s^2 2s^{2\,1}S_0)$ of Be-like ion to all possible levels of Li-like ions is described by the inner electron impact excitation channels schematically as following,

$$1s^2 2s^2 + e \rightarrow 1s 2s^2 nl + e. \qquad 2 \leq n \leq 12;\ 0 \leq l \leq 4. \tag{2}$$

The total EA cross section for level g is,

$$\sigma_g^{EA} = \sum_j \sigma_{gj}^{ex}(E) B_j^a, \tag{3}$$

where $\sigma_{gj}^{ex}(E)$ is the cross section for electron impact excitation of inner-shell from level g to the autoionization level j as a function of the incident electron kinetic energy E, and B_j^a is the branching ratio for autoionization from the level j. B_j^a is given by

$$B_j^a = \frac{\sum_k A_{jk}^a + \sum_{j'} A_{jj'}^r B_{j'}^a}{\sum_k A_{jk}^a + \sum_i A_{ji}^r}, \tag{4}$$