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TRANSFER-LOSS PROCESS IN 0.2- 2 MeV/u O^{5+} + He COLLISIONS

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We performed calculations of transfer-loss probability and differential cross section within the framework of the independent particle model (IPM). The initial and final configurations for the studied process are: O^{5+} ($1s^22s$) + He → O^{5+} ($1s2s2p$) + He^+ + e^- . For the projectile final state there exist three $1s2s2p$ alternatives, with the spectroscopic notation ^4P, $^2P_-$ and $^2P_+$. One of the possible mechanism resulting in these final states, is the so-called transfer-loss (TL) process in which the ionisation of the projectile 1s electron occur simultaneously with the transfer of a target 1s electron to the projectile 2p subshell. The TL results for the production of the ^4P, are compared with older measurements by Toth *et al.* obtained using the method of zero-degree Auger projectile electron spectroscopy [1]. Our result is smaller by a factor of 2 comparatively with experimental data.

Introduction

The study of projectile ion states by state-selective zero degree Auger projectile spectroscopy is a sensitive method for studying the fine details of the collision mechanisms. For more complicated processes, there are existing experimental data [1] in the literature, which need to be understand quantitatively.

In the present work, we make an attempt to interpret and describe the transfer-loss process within the framework of the IPM. We also report the first set of extended calculations performed for O^{5+} projectile impinging on He targets. The experimental data [1] for our investigated system are obtained with the high resolution technique of zero-degree Auger projectile spectroscopy. The experimentally studied KLL Auger transitions, where TL ought to contribute at low impact energies to the production of the $1s2s2p$ parent configurations, were $1s2s2p$ $^2P_-$ (parent state: $1s(2s2p\ ^3P)\ ^2P$), $1s2s2p$ $^2P_+$ (parent state: $1s(2s2p\ ^1P)\ ^2P$), $1s2s2p$ ^4P, and $1s2s^2$ ^2S. The final ionic state for all the Auger transitions is $1s^2$ ^1S.

In this study, we restrict our considerations to the determination of the TL contribution to the ^4P state only. The TL process contributes mostly at low projectile energies, where the transfer probability is dominant. It falls off rapidly with energy beyond the threshold for the dielectronic excitation process (eeE). TL is a two step process, which consists of the transfer of one electron from the target to the 2p states of the projectile and a simultaneous ionization of one of the 1s projectile electrons. It can give rise to all the $^2P_-$, $^2P_+$, ^2S and ^4P states.

We also should consider processes of more than two-steps, which may also lead to the same final configuration. We consider here only one such process, the *double transfer and loss* (T^2L) process followed by autoionization: a double electron transfer to empty projectile shells with n>2, with the simultaneous loss of one projectile K-shell electron, resulting in a $1s2sn_xl_xn_yl_y$ configuration. It is worth noting that at these lower projectile velocities, *only* TL and T^2L may contribute to the production of the ^4P state because spin-flip is practically forbidden.

Methods of Calculation

In general, two- or more-electron transitions occurring simultaneously may be considered as a correlated process. However, within this study, we shall apply the independent particle model (IPM) to all the calculations. Our basic goal is to study, whether the IPM is able to reproduce the main tendencies of the experimental data, or even provide a quantitative agreement with them. Let the transfer probability P_T represents the process He (1*s*) -> O^{5+} (2p_m), while the loss probability P_L, the O^{5+}(1*s*) -> O^{6+}(*continuum*) transition. If both probabilities are small, within the framework of the IPM, one may approximate the transfer loss probability at a particular impact parameter *b* as the product of the transfer (capture) and loss (ionization) probabilities:

$$P_{TL}(b) = P_T(b)P_L(b) \quad (1)$$

We are more interested, however, in calculating the probability for the production of an uncoupled determinant state, e.g., $| \ 1s\uparrow 2s\uparrow 2p_m\uparrow >$, for the projectile ion. Accordingly, the transfer and loss probabilities can be written as:

$$P_T^{2p_m} = P_{He(1s)\to O^{5+}(2p_m)}\left(1 - P_{He(1s)\to O^{5+}(any\ shell)}\right), \quad (2)$$

and

$$P_L = P_{O^{5+}(1s)\to O^{6+}(continuum)}\left(1 - P_{O^{5+}(1s)\to(any\ state)}\right)\left(1 - P_{O^{5+}(2s)\to(any\ state)}\right). \quad (3)$$

where the terms in large parentheses represent the probabilities that no other events happen, which may destroy the studied configuration. For the “any state” probabilities we consider the excitation from the ground state of O^{5+} into a set of excited and continuum states, and "any shell" represents an additional capture to oxygen.

The electron transfer and the target ionization probabilities have been calculated within the framework of the continuum-distorted wave (CDW) approximation [2]. The projectile excitation and ionization probabilities (right side of Eq. (3)) were calculated in the framework of a first order semiclassical approximation (SCA) using the code of Schiwietz [3] by properly taking into account the screening effect due to the electrons of the neutral target [4]. Both CDW and SCA calculations have been performed in first order. Since the calculated one-electron probabilities were sometimes large (in some cases larger than unity), we utilized a correction introduced by Sidorowich et *al.* [5] to keep unitarity in such cases.

Finally, the TL cross section for the above determinant state is given by:

$$\sigma_{TL}^{1s\uparrow 2s\uparrow 2p_m\uparrow} = \\ = 2\pi\int_0^\infty db\, b\, P_{TL}^{1s\uparrow 2s\uparrow 2p_m\uparrow}(b) \ . \quad (4)$$

In the calculation of the Auger production cross section at the specific angle of zero degrees, for the ^{4}P state one should pay careful consideration to the angular momentum coupling schemes, the de-alignment effects, and the Auger yields. This way, the calculated Auger-production cross sections may be directly compared to the single differential cross sections extracted from the measured Auger line intensities of the specific state of interest.

Results

The calculated zero-degree single differential Auger production cross-sections for Li-like O on He in the 3-10 au. projectile impact velocity regime is compared to the experimental data [1] for the ^{4}P Auger transition in Fig.1. As already known, at higher energies, the ^{4}P state is produced by the mechanism of exchange dielectronic excitation (eeE) [6, 1]. At lower energies, we expected the TL [7] and T^{2}L processes to dominantly lead to the production of the ^{4}P state. Though we have not obtained a good quantitative agreement, the present calculations support this model for He target. The projectile-energy dependence of the data is well reproduced by the calculation for the studied system. The difference between the measured and calculated cross sections most likely originates in the present CDW calculations for electron capture. The calculated electron loss cross sections alone are in good agreement with experiments [8]. In the present work, we emphasize the principles of our elaborated IPM calculation method. The extension of the calculations to other collision systems and other Auger states is in progress.

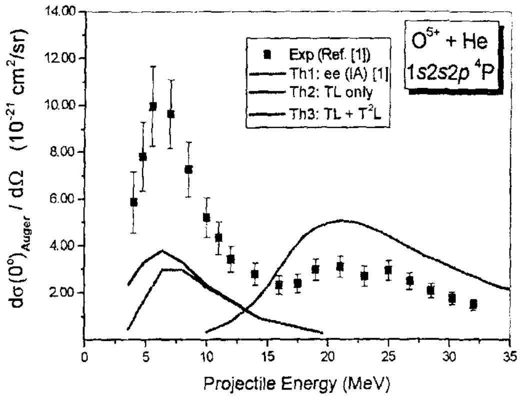

Fig. 1: Auger zero-degree single differential cross sections for the production of 1s2s2p ^4P states in O^{5+} collisions with a He target. Symbols: ■ experimental data [1]; Solid line: scaled dielectronic excitation (eeE) including exchange based on the impulse approximation (IA) [1]; Dashed line: present transfer-loss (TL) calculation; Dotted line: sum of the TL + T^2L contributions.

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ПРОЦЕСИ З ВТРАТОЮ ПЕРЕНОСУ В ЗІТКНЕННЯХ 0.2- 2 MeV/u O^{5+} + He

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У рамках моделі незалежних частинок нами виконано розрахунки ймовірності втрати переносу та диференціального перерізу. Початкова й кінцева конфігурації досліджуваного процесу є такими:: O^{5+} ($1s^22s$) + He → O^{5+} ($1s2s2p$) + He^+ + e^- . Для кінцевого стану налітаючої частинки існують три $1s2s2p$ альтернативи зі спектроскопічними позначеннями ^4P, $^2P_-$ і $^2P_+$. Одним з можливих механізмів, що веде до цих трьох кінцевих станів, є так звані процеси втрат переносу, в яких іонізація 1s-електрона налітаючої частинки відбувається одночасно з перенесенням 1s-електрона мішені на 2p-підоболонку налітаючої частинки. Результати з урахуванням втрати переносу при утворенні ^4P порівняно з більш ранніми вимірюваннями Товта та ін., одержаними методом електронної Оже-спектроскопії для налітаючої частинки при нульовому куті. Наші результати вдвічі менші в порівнянні з експериментальними даними.