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Obvious Evidence of TS2 Mechanism in Ar (e, 3e) Experiment

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Abstract: Through comparing the Ar (e,3e) double ionization experimental results at low collision energy with the theoretical calculation based on the first Born approximation which include the first order mechanisms SO and TS1, the symmetry breaking about the direction of the momentum transfer shows that the non-first order effects (such as two-step 2 mechanism) play an important role.

Key words: (e,3e); double ionisation; five-fold differential cross section

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1 Introduction

(e,3e) experiments are kinematically complete double ionisation (DI) experiments by electron impact, because the energies and angles of all participating particles are determined in the final state. In these experiments the fully five-fold differential cross sections are measured [1]. Such studies of the DI processes are the most sensitive probe to understand the dynamical electron-electron correlation during the collision and the DI mechanisms, which are unsolved so far [2]. The improvements in the electron analyzers and detectors as well as the introduction of multi-parameter coincidence measurements [3-5] resulted in a noticeable progress in the amount of experimental information and quality of the obtained data. But large discrepancies still exist between experiment and theoretical predictions. Therefore, more experimental data are needed to confirm the previous experimental results, to extend the available information to new kinematics or different targets and to stimulate the development of theory.

There are 3 collision mechanisms in (e, 3e) theoretical calculation, such as SO, TS1 and TS2. In the SO mechanism, the colliding electron interacts with and ejects only one of the target electrons while the second one leaves the target because of the resulting modification of the Coulomb forces. In the TS1 mechanism the incident electron first ejects one of the target electrons. This electron acts as a new incident electron to knock out the second of the target electrons. In the non-first order mechanism, such as two-step 2 (TS2), the colliding electron interacts successively with two different target electrons, ejecting them one by one.

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In this paper, the attention is focussed onto the comparison between the shape of the angular distributions measured in the experiments and predicted by the calculations, which shows that the non-first order effects (such as two-step 2 mechanism) play an important role since the symmetry breaking about the direction of the momentum transfer.

2 Experiment and Results

The multiparameter multicoincidence (e, 3e) spectrometer and the experimental procedure have been described by Duguet et al 1998. It consists of a telefocus electrostatic gun[6], a capillary gas inlet nozzle, a cylindrical analyzer with the associated optics and channeltron detector, and the dual toroidal analyzers equipped with two-dimensional, resistive anode position sensitive detectors (PSD). Each toroidal analyzer collects the ejected electrons in the collision plane, within an angular range of about 140°. These components are placed in a vacuum chamber with a working background pressure of about 10^{-4} Pa.

In this work, the Ar (e,3e) relative cross sections have been obtained by fixing all the kinematical parameters: the incident energy $E_0 = 561.4$ eV, the scattered electron energy and angle are $E_a = (500 \pm 6)$ eV and $\theta_a = +6.5°$, respectively. The corresponding momentum transfer is $K = 0.8$ arb. unit, in the direction $\theta_K = 300.3°$. The ejected electron energies are $E_a = E_b = (9.0 \pm 1.5)$ eV.

The experimental results are compared with calculations based on the first Born approximation which include the first order mechanisms SO and TS1. The contributions of the three Ar^{2+}-ion final states have been added with equal weights. This is certainly legitimate for the closely lying ^3P and ^1D states, but might be subject to some caution for the ^1S state. The model calculations make use of the approximate BBK model[7] which describes the two ejected electrons by a product of two Coulomb waves and the Gamow factor. The two Coulomb waves describe individual electrons being subject to the nuclear potential (the nuclear charge is here $Z = 2$), and the Gamow factor takes into account the mutual repulsion between the two ejected electrons. The frozen-core approximation is also used in order to reduce the N-electron-target problem to a six-electron-problem[8]. These six electrons are those of the initial state $3p^6$. Then, by considering low momentum transfer, $K < \sim 1$ arb. unit[9], this six-electron problem is reduced to a problem of two active electrons (which will be ejected after the collision). The initial state is calculated by superposition of different configurations[10] according to Clementi and Roetti's[11] tables. This approximate BBK is not a numerically intensive method like the CCC approach[12,13], however it was shown to be able to give the correct angular shape in earlier

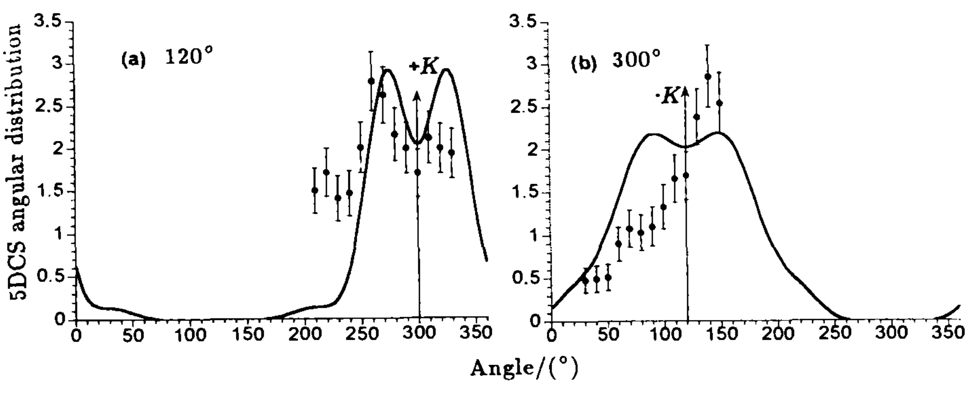

图 1 5DCS angular distributions in the fixed ejected angle mode. (a) $\theta_{fix} = 120°$, in the $-\boldsymbol{K}$ direction. (b) $\theta_{fix} = 300°$, in the $+\boldsymbol{K}$ direction. Full line: FBA-approximate BBK calculations. Full dots: experiments. The error bars are one standard deviation statistical error. All data in this figure are reported with the same relative scale.

(e,3e) experiments[9]. Moreover it can be applied to any configuration of the doubly charge ion states while, at present, the CCC approach has been used only for ns^{-2} and $ns^{-1}n's^{-1}$ states.

We show 2 special plots to compare the experimental with the theoretical results, where θ_{fix} matches the $\pm\boldsymbol{K}$ directions, which are depicted in Fig. 1(a) and(b). They are of a particular interest, because any first order model in the projectile-target interaction (SO and TS1 mechanisms) must yield, under these conditions, a symmetrical distribution with respect to $\pm\boldsymbol{K}$, as shown by Dal Cappello and Le Rouzo[14]. The theoretical results of our first order, approximate BBK model do indeed exhibit such symmetry in Fig. 1(a) and(b). In contrast, the experimental distributions do not. Such symmetry breaking can only be explained by invoking non-first order interactions, such as the TS2 mechanism, and hence constitutes an obvious evidence for the presence of strong non-first order effects (ST2 mechanism).

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Ar (e,3e)实验中 TS2 机制的明显证据

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摘　要：通过比较 Ar 在低碰撞能量下的(e,3e)双电离实验结果和基于包含一次作用机制 SO 和 TS1 的一阶波恩近似的理论计算结果，表明在动量转移方向上对称性的破坏显示非一次效应(例如二型两步作用机制)起非常重要的作用.

关 键 词：(e,3e)；双电离；五重微分截面