ELECTRON IMPACT IONIZATION OF HELIUM [(e,2e) & (e,3e)] INVESTIGATED WITH COLD TARGET RECOIL-ION MOMENTUM SPECTROSCOPY

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INTRODUCTION

One of the most fundamental tasks of nowadays atomic physics is the investigation of the dynamics in many-body systems. Its understanding is fundamental for a detailed treatment of practically all complex systems ranging from the simplest three-body problem, a charged projectile colliding with a hydrogen atom, via large molecules up to macroscopic structures of daily live. These many-body effects in systems governed by the Coulomb force (often called correlations) play a dominant role in atomic multiple ionizing reactions. Thus, already a study of double ionization can serve as a tool to investigate the specific many-body properties of bound and continuum wavefunctions as well as of the collision process itself.

In these investigations, fully differential cross sections obtained in kinematical complete experiments are the most stringent test for theoretical calculations. On this level, only very recently considerable experimental and theoretical progress has been made in the field of double ionization induced by absorption of a photon. For the pioneering work on helium double photoionization see Schwarzkopf *et al*[1] and Huetz *et al*[2], for some recent work see Dörner *et al*[3]. Now, more complex processes find rising interest, as double ionization in high energy Compton scattering, where at a given photon energy now a broad range of energy- and momentum transfers has to be considered[4], and double ionization from charged particle impact, as the (e,3e) experiment for electron impact, where additionally to Compton scattering now a fourth Coulomb particle, the projectile, has to be considered. For heavy ion impact, Moshammer *et al*[5] recently reported the first kinematically complete study of helium double ionization.

Experimentally, the kinematical completeness of an (e,3e) experiment with 4 outgoing particles requires a determination of 12 momentum components. Three of them can be deduced by applying the conservation law of vector momentum and a fourth from energy conservation in the case of a known final ionic state (like in helium double ionization).

equivalent to a detection and momentum analysis of three outgoing particles. Historically, the first method applied was the triple coincident analysis of the electrons in independent analysers [6]. With the advent of multidetection techniques based on position sensitive channel plate detectors (PSCD) a dramatic increase of coincidence acceptance and therefore double ionization detection rate could be realized, as with the help of a multi angle toroidal analyser for the emitted electrons [7]. By momentum conservation, the momentum determination of the recoiling ion is equivalent to the analysis of one electron. This fact is used by the technique of cold target recoil-ion momentum spectroscopy (COLTRIMS) [8]. It is based on *imaging techniques*, now applying extraction fields that are projecting the recoil-ion and one ejected electron onto PSCDs. This setup yields in a kinematical complete investigation of single ionization [(e,2e)] with a determination of both momentum vectors. In using this imaging principle, another dramatic increase of coincidence acceptance is achieved, which can be as large as a full 4π coincidence solid angle for low energy electrons. Therefore, the COLTRIMS technique is very efficiently suited for a visualization of the overall structures of the multi-dimensional distribution of the differential cross sections [9]. It is complementary to the 'pure' electron spectroscopy, where due to the smaller combined solid angle only well selected parts of the complete differential cross section as a whole can be studied. This selectivity can be advantageous for a study of special processes which take only very small regions in the total cross section.

This work describes in a status report the realization of an kinematical complete experimental investigation on single [(e,2e)] and double ionization [(e,3e)] of helium after electron impact at 550 eV based on the COLTRIMS technique. In this attempt, the scattered projectile is detected as the third particle in a cylindrical analyser. This is complementary to another COLTRIMS approach to (e,3e), where both ejected electrons are detected in a double ionization [10]. As the analysis of our experiment is not yet fully completed, here we give only first results.

EXPERIMENT

The COLTRIMS technique is based on the use of a localized, internally cold target provided by a super sonic helium jet. Here, the expansion is made from 15 bar via two stages (several 10^{-2} and 10^{-5} mbar, respectively) into the scattering chamber. The target density is several 10^{11} atoms/cm^2, its diameter was 1 mm. The jet was intersected with an electron beam produced by a standard oszilloscope gun at a kinetic energy of 550 eV with a diameter of approximately 1 mm.

A schematics of the COLTRIMS spectrometer is shown in figure 1. In this experiment, an electrostatic field of 3.3 V/cm is projecting the recoiling ions onto the PSCD with a solid angle of $\Delta\Omega = 4\pi$. From their known trajectory at a given detection position and Time-of-Flight (TOF), the ion momentum vector can be reconstructed with a resolution of < 0.1 a.u.. The ion momentum spectrometer was equipped with a three dimensional focussing to ensure a detection of ions with identical momentum but different starting positions within the target volume at the same TOF and position on the PSCD.

Emitted electrons are detected on a second PSCD opposite to the ion detector. It was mounted at a distance of 2 cm from the target to ensure a large detection solid angle. For the momentum determination, the same principle as for the ions is applied resulting in a momentum resolution < 0.1 a.u., too. At the extraction field used, electrons up to an energy of 3 eV are detected with the full 4π solid angle. For larger electron energies in the plane parallel to the detector surface ($y - z$ plane) the acceptance is decreasing, approaching the geometric solid angle of 10% of 4π for $E > 10$ eV.

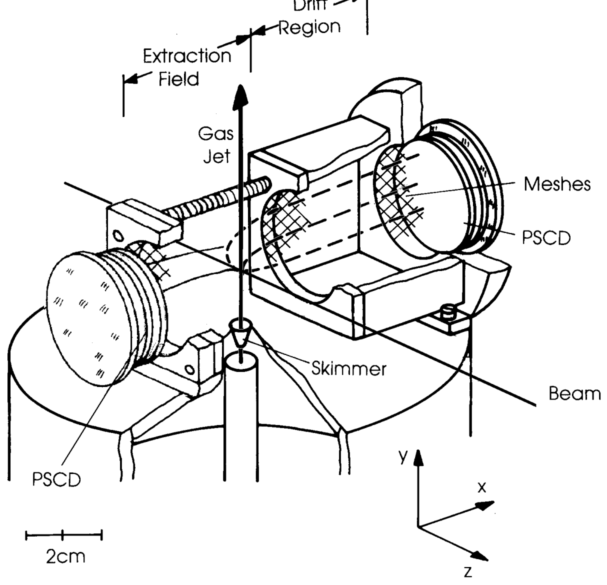

Figure 1. Sketch of the COLTRIMS spectrometer.

Scattered projectiles were analysed in a cylindrical analyser centered at 0° direction in a triple coincidence with the ion and ejected electron. Scattering angles between $\pm 3^\circ$ in horizontal (x-) direction were accepted, which were determined by a third PSCD. The direct beam left the spectrometer before reaching the detector through a slit into a Faraday cup outside the spectrometer. Due to background problems arising from secondary or backscattered electrons traveling from the entrance slit into the COLTRIMS spectrometer, the slit was removed during the measurement. Thus, projectile energy loss and projectile scattering angle in the direction parallel to the energy dispersion of the spectrometer (vertical direction) are mixed. As a consequence, these quantities are not dispersively detected but only by means of a center value with a deviation determined by the spectrometer geometry. The energy acceptance was approximately from 75 to 220 eV projectile energy loss. The recoil-ion and the emitted electron TOF was determined with respect to the scattered projectile, whose TOF spread can be neglected.

FIRST EXPERIMENTAL RESULTS

Singe Ionization

Figure 2 shows the z- (longitudinal) momentum components of the recoil-ion $({p_z}^{\mathrm{He}^+})$ versus the ejected electron $({p_z}^{\mathrm{e}})$ for all detected triple coincidences with the projectile. The dominating structure is a diagonal ridge. In the events exactly on the diagonal the recoil-ion and the electron are strictly compensating their z-momentum components. In these cases, no significant momentum transfer from the projectile took place. An equivalent picture is also obtained for the x- and y-momentum component, respectively. This overall picture of a compensation of electron and ion momentum strongly resembles the dipole limit of photoabsorption. Due to its zero rest mass the photon causes negligible momentum transfer and only energy deposition into the target atom.

The deviation from the ridge is due to the combined momentum resolution of ≈ 0.1 a.u. and due a non-zero momentum transfer from the projectile. From the electron and recoil-ion

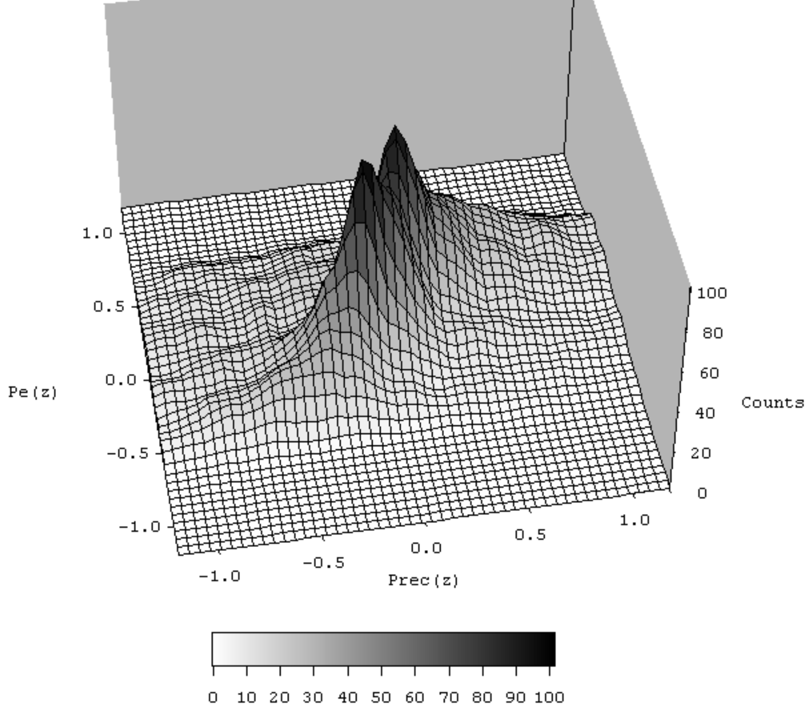

Figure 2. Recoil-ion momentum versus ejected electron momentum in z-direction for single ionization.

momentum distributions obtained simultaneously in this experiment angular distributions can be projected out with no regard to any specific scattering geometry for ejected electrons below 3 eV. These further results will be presented in a forthcoming publication.

Double Ionization

Figure 3 shows the recoil-ion momentum distribution in x-direction for all detected double ionization events (full curve) in comparison to the one for single ionization (dashed curve), which was divided by 20 for a better comparison. Again, similar spectrum is obtained

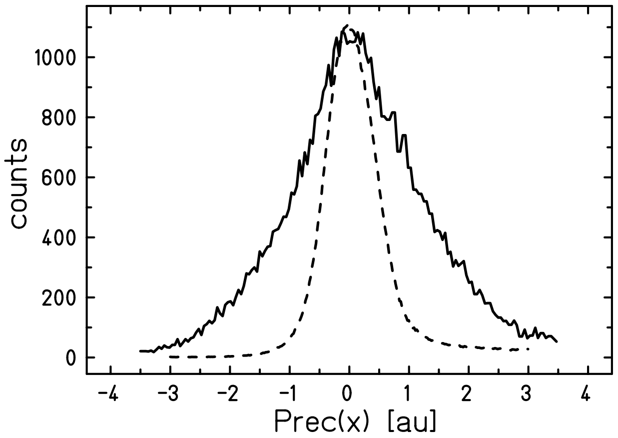

Figure 3. Recoil-ion momentum in x-direction for double ionization for all detected double ionization events (full curve) and for single ionization (dashed curve), divided by 20.

for the other momentum directions. Thus, the typical recoil-ion momenta are in double from the experimental recoil-ion momentum distribution confirms a conclusion of Lahmam-Bennani *et al* from their recent (e,3e) measurement on helium [11].

In comparing the momenta of one ejected electron versus the recoil-ion, for double ionization the correspondence obtained in single ionization (figure 2) is completely lost due to the many body nature of the collision. The next step will be a comparison of the recoil-ion momentum with the ejected electron momentum sum in double ionization.

FUTURE STEPS

The most prominent issue for a future measurement will be an improvement of the electron beam quality and the projectile spectrometer geometry to allow for an experiment done with the projectile spectrometer entrance slit. Then, in total 9 momentum components will be determined, yielding in a measurement of the energy balance. This allows to investigate larger target systems than helium, where the energy balance is not predefined.

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