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Differential ionization studies by positron impact

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Differential Ionization Studies by Positron Impact

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Abstract. The results of investigations of ionization of atoms and molecules by positron impact are presented, with particular focus on the electron capture to the continuum phenomenon. The application of recoil ion momentum spectroscopy in positron collisions are also discussed.

1. Introduction

During the last two decades several double and triple differential measurement of positron impact ionization have been carried out at UCL. One of the main aim of these studies has been to investigate electron capture to the continuum (ECC), a special case of ionization in which the ionized electron is strongly influenced by the positively charged projectile. This process, whose description requires higher order approximations [1] can be considered as an extrapolation across the ionization limit to highly-excited bound-states. In the case of ion impact, a sharp peak appears in the doubly-differential electron-spectrum around 0^o at a velocity which is close to that of the scattered projectile. Due to the positive charge of the positron, similar final state interactions are expected. However, due to the equal masses of the electron and the positron, different collision dynamics may occur resulting in scattering for positrons to much larger angles than for heavier projectiles.

Differential investigations, especially in positron physics, are very time consuming. In the case of traditional methods, the energy of the outgoing particle is measured using electrostatic/magnetic analyzers which examine the intensity at different energies separately. Similarly, the angular distribution is scanned by rotating the analyzer around the collision region. This can lead to data collection taking weeks if not months. In order to reduce the data collection time or increase the accuracy of the measured data, new methods must be employed. By measuring the time of flight of the fragments, information on their longitudinal energy may be obtained simultaneously, but this requires a start signal. There are some examples of simultaneous angular detection by placing detectors at different angles (e.g. [2]). A recently developed system, called Cold Target Recoil Ion Momentum Spectroscopy (COLTRIMS) [3], combines the advantages of both above mentioned methods by measuring the energy and angular distribution of the recoil ion simultaneously over the full 4π-solid angle. Fig. 1 shows this principle. When the scattered projectiles are recorded in coincidence with the outgoing fragments, a kinematically complete picture can be determined about the correlated motion of atomic and molecular breakup processes. This method has been successfully used with ions, electrons and photons as projectiles (e.g. [4,5] and references therein).

In this report, results for double and triple differential cross-sections for positron impact ionization, measured using traditional methods, will be presented. This will be followed by a discussion of the requirements placed upon an experimental setup by the COLTRIM method and, finally, the progress made toward such a system will be briefly outlined.

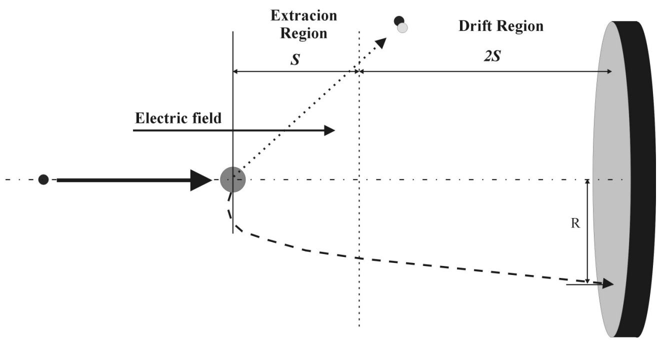

Figure 1. Basic principle of the recoil ion method.

2. Results

Initially, investigations of the doubly-differential electron energy spectra found no peak which could be associated with ECC [6,7]. Aided by theoretical investigations [8], it was surmised that the wide angle scattering of the light projectile from Ar would spread the ECC peak over a broad range of angles, in contract to the sharp cusp observed by ion impact at around 0^o with respect to the beam direction. For this reason, a more sensitive (triply-differential) measurement was performed by measuring coincidences between the scattered positron and the ionized electron and a lower-Z target (H_2) was used. At 100 eV projectile energy, a small broad peak was found in the electronic spectrum, the first clear experimental demonstration of the occurrence of ECC by positron impact [9]. Theoretical calculations were soon able to reproduce these findings [10,11]. However, at 50 eV impact energy the electron spectrum was observed to be shifted to a lower energy by 1.6 eV relative to the theoretical value [12]. Further investigations showed that a similar shift but towards higher energies occurs in the corresponding energy spectrum of the scattered positrons (Fig. 2) [13]. Although not fully understood, a possible explanation of these surprising findings is that the polarization of the positron-electron pair in the positive Coulomb field of the residual target ion causes the ejected electron to be slowed down and the scattered positron to be accelerated.

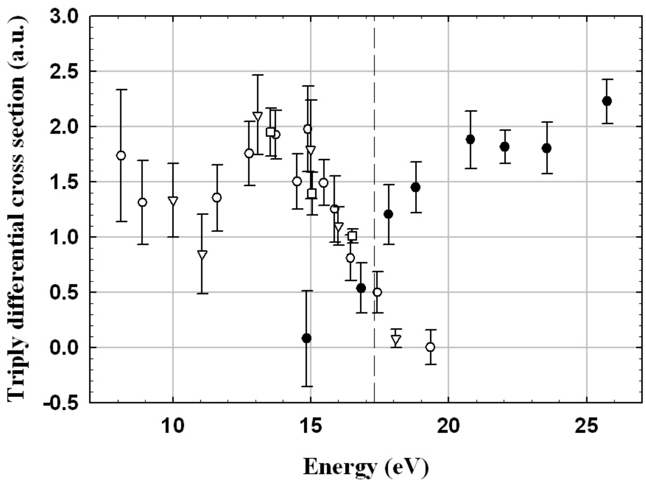

Figure 2. Experimental data of the triply differential ionization cross sections. Energy of ejected electron from 50eV e^+ collisions with, (o) H_2, (●) He and (▽) D_2. (●) indicates the energy of the scattered positrons from 50 eV e^+ - H_2 collision. The dash line shows where $v_{e+} = v_{e-}$.

Recently, the fragmentation of H_2O has been investigated around 0^o as a function of the energy loss of the e^+ projectile, at 100 and 153 eV impact energies [14]. H_2O is of special interest due to its strong dipole moment, which has been shown to cause significant forward scattering of electron projectiles [15]. The main aims of this work have been to investigate whether forward scattering enhances the probability of ECC around 0^o and to measure the intensity ratios of different fragments at various projectile energies. Fig. 3 shows the results for H_2O^+ fragments at 100 eV positron impact energy. No ECC peak has been found in the double differential electron spectrum, similarly to the earlier results obtained with Ar [6], indicating that the strong dipole moment of the water does not significantly enhance the ECC process for positron projectiles. However, a small shoulder around 28 eV energy loss has been recorded at both projectile energies. This structure may be consistent with the results of high resolution electron momentum spectroscopy ([16] and references therein), identifying 27.1 eV as the onset of a weak shake-up band connected with the $2a_1$ orbital.

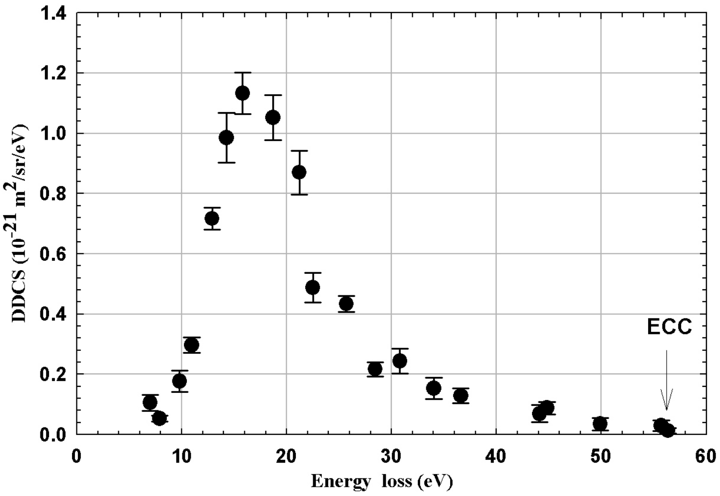

Figure 3. Energy loss spectrum of e^+ scattered projectile in coincidence with the H_2O^+ fragments. From 100 eV e^+ - H_2O collisions.

3. Discussion & Conclusion

At present, a number of groups (E.g. Williams *et al* [17], Caradonna *et al* [18]) are developing the first COLTRIMS apparatus for use with positron projectiles. The technique imposes stringent requirements upon both the projectile beam and target. To achieve the required position resolution, a parallel projectile beam with a diameter of approximately 1 mm or less is necessary. The typical diameter of an electrostatic positron beams is around 4 mm, due to the size of the moderator and the radioactive source. A high degree of accuracy is also required in the time of flight measurements. It may be possible to do this by chopping the beam (to obtain start pulses), but to obtain the required resolution the intensity of the beam would be reduced to an unacceptably-low level. For the target beam, the constraints are similar: the diameter must be small (~ 1 mm) and dense (10^{11}-10^{13} atom/cm^3); it must also have a small initial momentum distribution in order to resolve the small momentum transfer (0.3-4 a.u.) during collision. Yet application of the COLTRIMS method in positron physics has several advantages despite the technical difficulties. The 4π detection of the outgoing residual ions means that all the collision events can be detected, which greatly reduces measuring times. From the time of flight spectra, the longitudinal energy of the ions can be determined which yields information on the type of collision processes (ionization, capture to bound/excited

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states, etc.) whilst the ejection angle of the ions reveals the dynamics of the collision process especially when measured in coincidence with other fragments. Fig. 4 shows examples of the measurements which we plan to carry out in order to distinguish the ECC process from the Ps formation and measure the angular distributions of both processes. Here, the collision system under consideration is 100 eV e^+ - He and the extraction voltage of the ions is 3 V. The calculated time of flight can be seen on the ***x*** axes, while the ***y*** axes shows the angular deflection of the ions. From these data, the angular distribution of the Ps and the ECC process can be determined. These values are indicated on the figure.

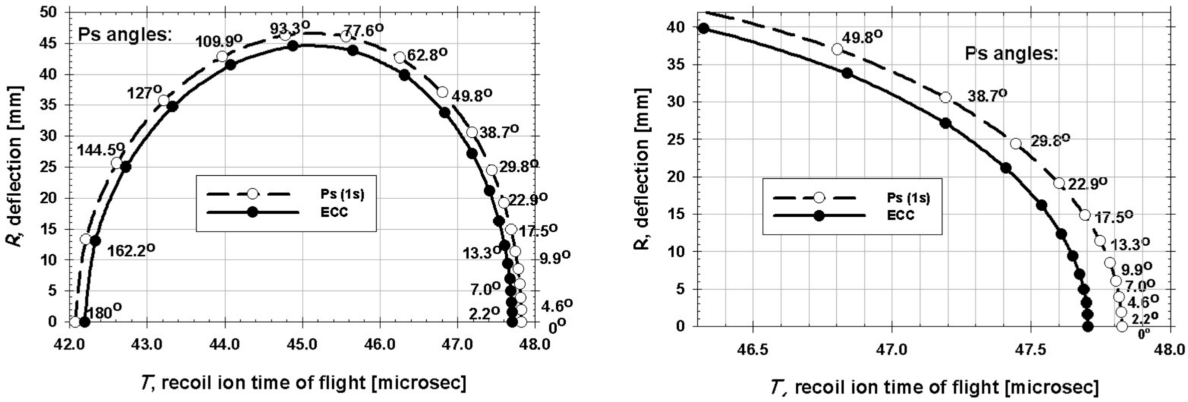

Figure 4. The calculated recoil ion time of flight and deflection from 100 eV e+ -He collisions. The numbers on the figure indicate the corresponding deflection angle of ECC/Ps fragments. The right graph shows the enlarged part of the forward scattered fragments.

To fulfill the afore mentioned requirements to undertake a COLTRIMS experiment, a new positron beam line has been developed. A Na-22 radioactive source and W mesh moderator have been combined with an electrostatic lens system to produce a 5 keV positron beam, which is tightly focused onto a 1000Å W foil remoderator. From here, the beam is transported by another electrostatic lens system to the intersection with the target beam. Included in this system is a cylindrical mirror deflector to separate the high energy beta and gamma particles from the low energy positron beam. The target is produced by a supersonic gas jet system. The interaction region is located inside an extraction spectrometer which accelerates the residual ions onto a 80 mm diameter position sensitive detector. A fuller description of this system can be found in the paper of A.I. Williams *et al* [17]. Recently a 1mm diameter e^+ beam at the interaction region has been achieved. The next step in the development of the system will be the testing of the extraction spectrometer.

Acknowledgments

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