Progress Towards a Positron Reaction Microscope

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Abstract. The progress toward the construction of a positron reaction microscope is outlined. The design principles of an electrostatic lens system used to focus and transport the positron beam with a ∼ 1 mm diameter spot are briefly discussed. Also presented here are the results obtained from the characterisation of the supersonic gas jet assembly, an increased peaking factor of ∼ 4 has been observed along with a centerline density of ∼ 10¹² cm⁻³.

1. Introduction
The integrated cross-sections for direct ionization and positronium formation have been studied extensively for the inert atoms [1, and references therein] and some molecules [2–5]. However, differential measurements (i.e. resolved in scattered energy and angle) are very scarce being constrained to a handful of measurements over very limited ranges [e.g. 6, 7]. This type of study is expected to contribute to the many fields of investigation which involve positrons, including among others, analysis of energetic events in the galactic center [8], and medical applications such as PET scanners [9]. Reaction microscopes (henceforth referred to as RM) have been used for several years to determine the integral and differential cross-sections of ionizing/fragmentation processes between various projectiles (e.g. photons, ions and anti-protons) and target atoms/molecules [e.g. 10]. However as yet, they have not been used in conjunction with positron impact. The RM setup consists of a projectile beam crossed with a supersonic gas jet target inside a recoil ion spectrometer. The reaction products are usually imaged with one or two Position Sensitive Detectors (PSD). The projectile beam and the supersonic gas jet target have well defined velocities so that the initial conditions of the scattering process are well defined. The recoil ion spectrometer guides the reaction products onto the PSD. This allows the determination of the angular and energy distributions of the product particles.

The ability to determine fully differential cross sections for low energy positron impact on atoms, would allow the study of many interesting phenomena. For example electron capture to the continuum (ECC), which is an ionization process in which the emitted electron is captured by the projectile to a low-lying continuum state. This was first observed in collisions using proton and heavy ion beams [11, 12], where cusp-like structures were seen in the differential cross-section when the velocity of the emitted electron was equal to that of the projectile. This phenomenon has also been observed in positron - H₂ collisions [13]. Interestingly, at 50 eV incident e⁺ energy, the emitted electron energy distribution was found to be shifted to lower values in comparison with theory by ∼ 1.6 eV [14]. The reason for this is still not fully understood.

In the following report, preliminary results are presented for the characterisation of the positron beam and a helium supersonic gas jet.
2. Experimental Method & Results

2.1. Beam Transport

The fast positrons emitted from a Na-22 source are impinged onto a tungsten mesh moderator. The re-emitted mono-energetic positrons are transported by an electrostatic field produced by a lens system, which is illustrated in Fig. 1. As shown, the majority of the lenses are made up of three cylindrical elements. This three element design is more commonly known as a zoom lens, as the positions of the object and image can be maintained while the overall acceleration is changed [15]. The beam is focused to a ~1 mm spot onto a remoderator (100 nm W foil), from which secondary electrons are also collected to use as a timing signal [16]. A cylindrical mirror analyzer is then used to turn the beam through 90°, which moves the interaction region out of the line of sight of the source and separates out any fast particles emitted from the source. The beam finally intersects the supersonic gas jet at the interaction region.

2.2. Supersonic Gas Jet

Supersonic gas jets are based on the concept of letting a high pressured gas (~ 9 bar) expand through a small nozzle into a low pressure chamber ~ 10^-2 mbar [17]. The resulting supersonic expanding gas can then be collimated with a skimmer to form a well defined jet, as depicted in Fig. 2. Due to the large gas flow rates into such systems several stages of differential pumping are required to keep the pressure in the interaction region low. Such a setup is shown in Fig. 2. Using this type of system, gas jet densities of ~ 10^{13} cm^{-3} have been obtained at the interaction region in previous experiments [18]. In the current setup, it should also be possible to obtain a momentum spread in the transverse direction of ~ ±0.04 a.u, in comparison with the momentum spread of helium at room temperature which is ~ ±2.7 a.u.

An important property of a supersonic gas jet is its peaking factor, which is a measure of the angular distribution of the flux from the nozzle. The angular distribution of gas from the nozzle in the current setup can be seen in Fig. 3. The \( \cos^4(\theta) \) distribution which fits the data well, relates to a peaking factor of ~ 4 [19]. This is a factor of 2 better than usually obtained [20]. This may be due to the use of a 50 \( \mu \)m electron microscope aperture as the nozzle. It is well known that such apertures have a divergent exit, which may enhance the peaking factor [19].
Another important property of the supersonic gas jet is the centreline density, \( n_c \), at the interaction region. This can be calculated from the pressure rise in Chamber 4, \( \Delta P_4 \), using Eqn. 1 [18]:

\[
n_c = \frac{\Delta P_4 \cdot S}{v_\infty \pi r^2 k_B T},
\]

where \( S \) is the effective pumping speed, \( v_\infty = \sqrt{5k_B T / m} \) is the final longitudinal velocity, \( r \) is the radius of the jet in the interaction plane and \( T \) is the temperature. Initial measurements of the centreline density of the current system have been carried out using this method, with the following initial conditions: 4 bar nozzle pressure; \( S \sim 500 \) l/s; \( r = 6 \) mm; \( T = 298 \) K. The maximum observed pressure rise in chamber 4 was \( 1.5 \times 10^{-7} \) mbar which gives \( n_c \sim 10^{-12} \) cm\(^{-3} \), about a factor of \( \sim 5 \) smaller than calculated from theory.

2.3. Detection

A recoil ion spectrometer will be used to extract the ions from the interaction region onto a RoentDek DLD80 position sensitive detector [21]. Using the DLD80 detector a 100 eV positron beam, produced by the electrostatic lens system (Fig. 2) was imaged and is shown in Fig. 4. The full width at half maximum (FWHM) is \( \sim 1 \) mm and \( \sim 200 \) remoderated positrons per second have been obtained from a 10 mCi Na-22 source.
3. Conclusion
The progress made towards the production of a positron reaction microscope has been outlined. The first characterisation measurements of the new supersonic gas jet assembly have been presented, along with the first image of a 1 mm positron beam produced with the new electrostatic lens system. Optimisation of the various components is in progress. The aim is to use the equipment outlined above to study fully differential cross-sections for positron-matter interactions. This will include a detailed study of electron capture to the continuum.

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