An electrostatic slow positron beam apparatus for positron scattering experiments

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Abstract. An electrostatic slow positron beam system has been developed for positron scattering studies. The apparatus uses a remoderator in reflection geometry in conjunction with an electrostatic hemispherical energy analyzer for the brightness enhancement. It is possible to determine absolute total scattering cross section values under magnetic field-free conditions down to a few mG. Measurement of the energy distribution of the positrons that are reemitted from the remoderator and total cross sections for positron-He scattering are presented.

1. Introduction

The scattering phenomena between positrons (e\textsuperscript{+}) and gas molecules are similar to those between electrons (e\textsuperscript{−}) and gas molecules at sufficiently high energies. At these high energies the cross sections have the same values for e\textsuperscript{+} and e\textsuperscript{−} scattering. There are, however, interesting differences at lower energies. Whilst the polarization potential is attractive for these two particles, positrons are repelled by the mean static atomic field. Consequently, the cross sections for e\textsuperscript{+} scattering are considerably smaller than those for e\textsuperscript{−} scattering. In addition, the positron is distinguishable from the electron in the target atom or molecule, and therefore exchange effects with the projectile are absent. Furthermore, processes of interest unique to positron scattering include the formation of positronium, the bound state of a e\textsuperscript{+} and an e\textsuperscript{−}.

The slow positron beams currently used in scattering experiments have far lower intensities than those for electron beams. Since the 1970s, several groups have developed magnetically confined or electrostatic slow positron beams for the measurement of scattering cross sections [1]–[17]. Hybrid beams have also been developed [14]. Though positron elastic differential and ionization cross sections have been measured using electrostatic beams [9]–[13],[17], most of the total cross sections have been determined under the influence of external axial magnetic fields. They have been corrected for the forward scattered positrons in the field which cannot be distinguished from unscattered positrons using theoretical angular elastic differential scattering cross sections.

In the present work, we have developed an electrostatic slow positron beam apparatus [18], where slow positrons were transported by an electrostatic lens system. In order to avoid the effect of stray magnetic fields, the apparatus was covered with \(\mu\)-metal shielding. Therefore, it was possible to determine the cross sections under magnetic field-free conditions down to a few
mG. In addition, a remoderator was used in the reflection geometry for brightness enhancement in order to produce a high quality beam with a small diameter and small angular divergence even at low energies. Most of the forward scattered positrons can be distinguished from the unscattered positrons and the cross sections are expected to be obtained without corrections, or with small corrections.

2. Apparatus and experimental approach

2.1. An electrostatic slow positron beam apparatus

A schematic diagram of the electrostatic slow positron beam apparatus is shown in Fig.1.

![Figure 1. Schematic diagram of the electrostatic slow positron beam apparatus.](image)

Positrons from a 360 MBq $^{22}$Na source capsule were moderated with an arrangement of 10 overlapping tungsten meshes. The wires of the meshes were thinned to about 10 $\mu$m in diameter by means of an electro-polishing treatment procedure [19]. The moderator meshes were annealed at 2100°C for a few minutes in a separate chamber by passing an electric current through a 25 $\mu$m tungsten foil, which encased them in order to remove bulk defects that may act as positron traps. The slow positrons emitted from the moderator were transported by several electrostatic lens elements constructed from aluminum alloy material. The beam was deflected using a 90° mirror analyzer, which was employed to separate the slow positrons from the high-energy positrons and $\gamma$-rays. The beam was then transported using further lens elements and focused onto a remoderator with an energy of 4 keV and a diameter of approximately 2-3 mm through an aperture in the electrostatic hemispherical energy analyzer. The remoderator was a tungsten single crystal foil of thickness 2 $\mu$m that had been previously annealed at 2100°C in the same chamber used to treat the mesh moderator. Positrons reemitted from the remoderator were deflected and energy selected using the hemispherical energy analyzer [20]. Backscattered positrons from the remoderator were eliminated in this procedure. The beam was transported to a 30.5 mm long gas cell, which had entrance and exit apertures 2 mm in diameter. Positrons that emerged from the cell were detected by a Channeltron.

All parts of the vacuum chamber were made from stainless steel. Three turbo molecular pumps were used with pumping speeds of 250 $\ell$/s for the electrostatic transport region, 400 $\ell$/s...
and 250 l/s for the scattering chamber. In order to prevent the effect of stray magnetic fields, the positron gun and the beam transport system were covered with μ-metal shielding. The remoderator, the electrostatic hemispherical energy analyzer, the cell and the Channeltron were also covered with a two-layer μ-metal shielding in the scattering chamber.

2.2. Measurements of the energy distribution of the reemitted positron

When positrons of several keV energy are incident on a single-crystal moderator, they rapidly lose their energies and approach thermal equilibrium in the lattice. In this work, the kinetic energy distribution of the positrons that diffused back to the surface and were reemitted were measured using the electrostatic hemispherical energy analyzer with an analyzer resolution of 40 meV. The results are shown in Fig.2. We determined the value of the positron work function for the tungsten single crystal remoderator to be -2.95 eV. The full-width at half-maximum (FWHM) of the peak was found to be 250 meV.

![Figure 2. The energy distribution of the reemitted positrons.](image)

2.3. Measurements of total cross sections for positron-He scattering

Absolute total cross sections for positron-He scattering have been measured using a linear transmission method. The energy resolution of the hemispherical analyzer was set at 2 eV in order to increase the count rates. The total resolution for the cross section measurements was 250 meV. The target gas was admitted into the cell via a manually controlled leak valve. The pressure at the center of the cell was determined using an absolute capacitance manometer and typical pressures ranged from 5.0 to 10.0 Pa. Preliminary cross section results are shown in Fig.3, in comparison with some previous measurements[7][16][21][22]. The present results are higher than other measurements in the energy region between 5 and 100 eV. The reason for this discrepancy is not known. Further investigation is necessary.

3. Conclusion

We have developed a magnetic field-free slow positron beam apparatus for the measurement of total scattering cross sections. The energy distribution of the slow positrons for the scattering experiments was found to be approximately 250 meV. Absolute total cross sections for e^+ -He in the energy range up to 100 eV have been measured. The preliminary results obtained are higher than other previous measurements.
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5. References

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Figure 3. Total cross sections for $e^+\text{-He}$ scattering.