First Observation of the Photodetachment of Positronium Negative Ions

The photodetachment of positronium negative ions, which are a bound state of one positron and two electrons, has been observed for the first time in the Slow Positron Facility. The ions were produced from a pulsed slow positron beam in the short pulse operation mode of the dedicated 55-MeV linac. Pulsed laser light with a high photon density sufficient for the photodetachment synchronized with the positron pulses was irradiated. The experimental field developed in the present work provides new opportunities for exploring the quantum mechanical three-body problem and developing energy tunable positronium beams.

More than 50 years ago, J. A. Wheeler [1] proposed the existence of several kinds of exotic systems composed of three particles of equal mass, bound via Coulomb interaction. The positronium negative ion (Ps^-) is the only system that has been observed so far [2]. Although many theoretical studies have explored the nature of Ps^-, for many years the only experiments have been measurements of the decay rate, limited by the extremely weak Ps^- intensity.

In 2006, a new method of generating Ps^- was developed [3]. Some of the slow positrons injected onto a clean tungsten surface lose their energy in the bulk, diffuse back to the surface and then are emitted as Ps^-. Although the formation efficiency was less than 0.01% in the first measurement, the efficiency has been dramatically enhanced to 1.25% by coating Cs atoms onto the tungsten surface [4]. Furthermore, coating with Na has been found to be as effective for Ps^- production and the effect lasts longer [5].

In the present work, we studied the photodetachment process using the crossed beam method of a pulsed Ps^- beam, produced by bombarding a Na coated tungsten surface with a pulsed slow positron beam at the Slow Positron Facility [6]. The advantage of using the pulsed slow positron beam is that synchronization with a high power pulsed laser which has a high photon density sufficient for photodetachment is possible [7]. The positrons with energy of 4.2 keV, high enough to prevent pulse widening, were transported to the chamber for observation of the Ps^- photodetachment. The chamber was evacuated to a pressure of 3×10^{-8} Pa. The target used to generate Ps^- was a polycrystalline tungsten foil of thickness 25 μm. It was annealed in situ at 1800 K and then coated with one monolayer of Na. The positrons were incident onto the target with an energy of 1.5 keV through a field-free region at a potential of 3.7 keV. The Ps^- ions emitted from the target were accelerated to 1.0 keV and annihilated into two γ-rays. The γ-rays were monitored by two Ge detectors mounted upstream of the target. The γ-rays were blue-shifted and thus identified easily (Fig. 2).

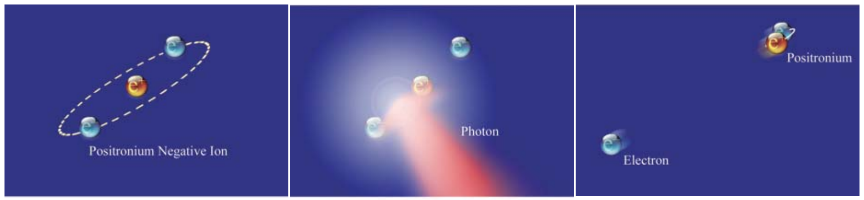

Figure 1
Photodetachment of the positronium negative ion.

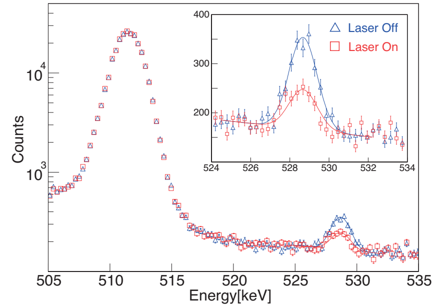

Figure 2
Annihilation γ-ray energy spectra with laser on or off. Each spectrum is normalized to the incident positron numbers [6].

The light used to photodetach the Ps^- was a fundamental wave of a Q-switched Nd:YAG laser synchronized to the positron pulses. The wavelength was 1064 nm, for which energy photodetachment is predicted to occur efficiently. The relative amount of para-positronium, which self-annihilates into 2γ, and ortho-positronium, which self-annihilates into 3γ, is 1:3. Thus, the Ps^- peak intensity will be decreased by 75% if the laser intensity is high enough and the overlap between the laser pulses and the Ps^- bunches is perfect.

Figure 2 shows the annihilation γ-ray energy spectra observed with the laser either on or off. The Ps^- peak intensity decreased by 57% with the laser on, indicating the Ps^- photodetachment. The lower limit of the Ps^- photodetachment estimated from the decrease is 2.1×10^{-17} cm^2, which is consistent with theoretical results [8].

The success of Ps^- photodetachment opens the door to a new era of studies on Ps^-. The production of an energy-tunable positronium beam using the photodetachment technique will also be feasible [9].

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