

# A Full Electrostatic High-Brightness Slow Positron Beam Apparatus Using a Remoderator in Conjunction with a Hemispherical Energy Analyzer

Kazuaki Nagumo<sup>a,\*1</sup>, Masamitsu Hoshino<sup>b</sup>, Hiroshi Tanaka<sup>b</sup> and Yasuyuki Nagashima<sup>a†</sup>

<sup>a</sup> Department of Physics, Tokyo University of Science, 1-3 Kagurazaka, Shinjuku, Tokyo 162-8601, Japan

<sup>b</sup> Department of Material and Life Science, Sophia University, 7-1 Kioicho, Chiyoda, Tokyo 102-8554, Japan

E-mail: \* kazuaki\_nagumo@imr.tohoku.ac.jp, † ynaga@rs.kagu.tus.ac.jp

**Abstract.** The development of a full electrostatic slow positron beam apparatus at the Tokyo University of Science is described. The performance of different types of material as the primary moderator and the energy resolution of the beam are detailed.

## 1. Introduction

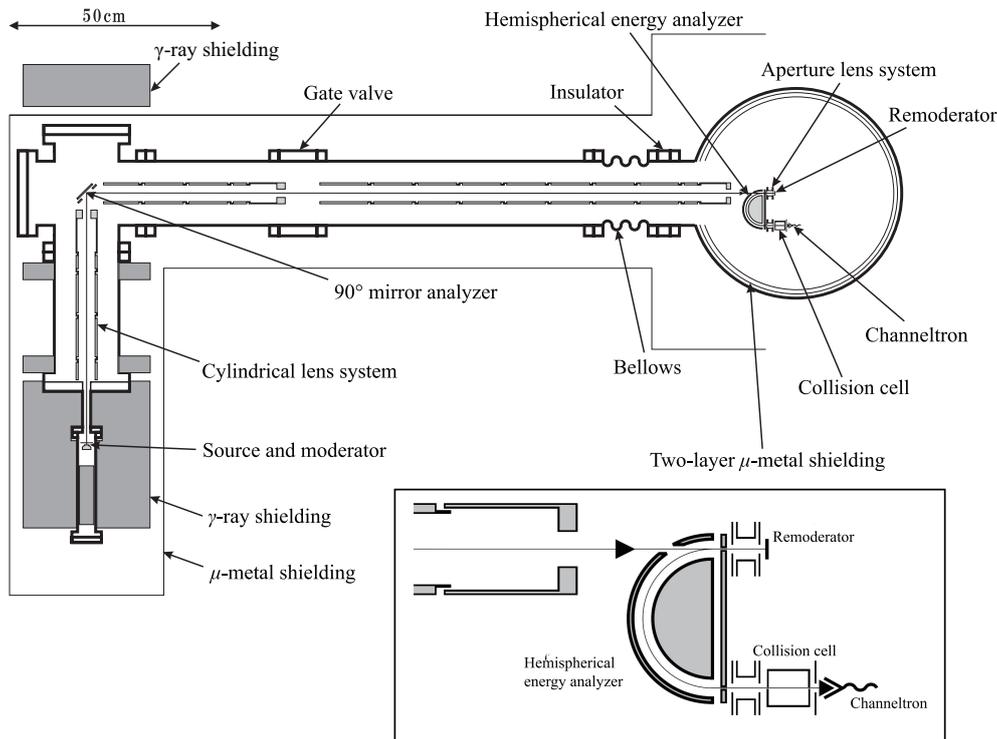
High quality slow positron beams are becoming increasingly necessary for various research fields using positrons[1]. Some of them, which include spin material research[2], positron microscopy[3][4], and positron scattering studies require or would benefit from the use of electrostatic beams. Recently, we have developed a full electrostatic slow positron beam apparatus at the Tokyo University of Science. This new apparatus uses a remoderator for brightness enhancement in conjunction with an electrostatic hemispherical energy analyzer. The details of the apparatus and its applications are presented in this paper.

## 2. Summary of the slow positron beam system

A schematic diagram of the slow positron beam apparatus is shown in figure 1. The slow positrons are produced from a <sup>22</sup>Na source with an activity of 400 MBq in combination with a tungsten mesh moderator as described in 2.1. The slow positrons emitted from the moderator are accelerated up to 5 keV by an electric field applied between the moderator and a tungsten mesh grid situated 5 mm in front of the moderator and are transported using several electrostatic lens elements made of aluminum alloy. The beam is deflected using a mirror analyzer in order to eliminate high-energy positrons and  $\gamma$ -rays from the positron source. The beam, of 5 keV, is then transported with further lens elements and focused onto a remoderator through an aperture of 5 mm in the outer shell of the hemispherical energy analyzer made of stainless steel. The radius of the outer shell is 44 mm and that of the inner shell is 33 mm.

<sup>1</sup> Present Address: The Oarai Center, Institute for Materials Research, Tohoku University, 2145-2 Narita, Oarai, Ibaraki 311-1313, Japan





**Figure 1.** Schematic diagram of the full electrostatic high-brightness slow positron beam system[5].

The positrons reemitted from the remoderator are deflected and energy selected by the hemispherical analyzer so that back-scattered high-energy positrons from the remoderator are eliminated. In order to guide the high-brightness slow positron beam from the exit of the hemispherical analyzer, electrostatic lens elements of molybdenum discs with a central aperture are used. The slow positrons are transported to a channeltron (BURLE 5901) for detection through a gas cell used in the measurement studies of the total scattering cross section for positrons[5][6].

In order to avoid geomagnetic effects, the beam transport chambers are enclosed in a single layer  $\mu$ -metal shielding box and two-layer  $\mu$ -metal shielding surrounded the experimental chamber.

### 2.1. Performance of different types of primary moderators

In the present study we have investigated the moderation efficiencies of three different types of material for the primary moderator: a single-crystal (100) tungsten foil, a polycrystalline tungsten foil and a tungsten mesh. The single-crystal and the polycrystalline foils of  $2\ \mu\text{m}$  thickness were purchased from Aarhus University. The mesh moderator is composed of 10 overlapping tungsten meshes which were thinned to about  $10\ \mu\text{m}$  in diameter by an electro-polishing treatment[7]. They were annealed at 2400 K for a few minutes in a separate chamber by passing an electric current through a  $25\ \mu\text{m}$  tungsten foil wrapping the meshes. Then, they were placed 2 mm in front of the source and were used in transmission geometry.

The intensity and the diameter of the slow positron beam obtained from the three different moderator types were measured at the remoderator position, without the hemispherical analyzer in place, using a micro-channel plate with a phosphor screen. The results are given in table 1.

**Table 1.** Positron rates and beam diameters of three types of moderators measured at the remoderator position by a micro-channel plate with a phosphor screen.

Primary Moderator	Positron Rate(count/s)	Beam Diameter(mm)
W(100)	1800	2
W polycrystalline	3200	2
W mesh	7000	3–4

Though the beam diameter was the same for the W(100) and the polycrystalline W, the count rate for the W(100) was lower than that for the polycrystalline W. The highest positron rate was obtained using the W mesh though the diameter was larger than the others as the angle of divergence was bigger. The W mesh was selected as the primary moderator as a higher intensity is a greater requirement at this stage.

### 2.2. Brightness enhancement

The diameter and divergence of most positron beams are generally limited by the geometry of the primary sources and moderators employed. High quality beams require not only small diameter but also the minimum possible spread in both angle and energy. This is quantified by the brightness,  $R$ , of the beam by

$$R = \frac{S}{\sin^2 \theta d^2 E}, \quad (1)$$

where  $d$  is the beam diameter,  $E$  is the positron energy,  $S$  is the beam intensity, and  $\theta$  is the angular divergence. The brightness of a particle beam is usually limited by the beam emittance and Liouville's theorem, which states that the volume occupied in phase space of the beam is constant under the influence of conservative forces. Thus the diameter of the beam can be reduced but at the expense of the angular divergence. During the positron remoderation process non-conservative forces are present and therefore the limitations of Liouville's theorem do not apply. Positrons are focused to a small spot and remoderated, resulting in a small sized beam with a low angular spread and a narrow energy distribution. Although the number of positrons is reduced by the remoderation process, the intensity is far higher than that of a beam produced using a collimator or an energy analyzer. In the present system, a tungsten (100) single-crystal foil of  $2 \mu\text{m}$  thickness is employed as the remoderator in the reflection geometry. It was previously annealed at 2400 K for a few minutes in a separate chamber by passing an electric current through a  $25 \mu\text{m}$  tungsten foil wrapping. The slow positron beam, of 5 keV, is focused onto the (100) surface of the crystal and the remoderated positrons are transported and energy-analyzed by the electrostatic hemispherical analyzer.

The use of this arrangement was motivated by the work of Fischer *et al*[8], who measured the energy distribution of reemitted positrons from various metals using a hemispherical energy analyzer. The advantage of using the combination of a remoderator and a hemispherical analyzer is that the beam diameter and the divergence are small enough to be for an adequately intense beam to be transmitted through the gas cell for the purposes required.

### 2.3. Energy resolution

The kinetic energy distribution of the positrons reemitted from the remoderator surface was measured using the hemispherical energy analyzer. In order to attain a high energy resolution with this small analyzer, an aperture of 1 mm diameter was placed at the exit of the analyzer and the mean pass energy was set at 3 eV, resulting in an analyzer resolution of 40 meV. The energy spectrum of the reemitted positrons from the remoderator can be obtained by sweeping

the potential of the remoderator, is shown in figure 3 of [5]. If we neglect the contact potential between the remoderator and the spherical analyzer, the positron work function for the W single-crystal remoderator is determined to be  $-(3.0 \pm 0.2)$  eV. The full-width at half-maximum (FWHM) of the peak is 250 meV[5].

### 3. Application of the full electrostatic high-brightness slow positron beam

Recently, the first magnetic field-free measurements of the total cross sections (TCS) for positron scattering have been performed using this positron beam system[5][6]. The TCS values were determined by the measurement of the transmitted beam intensities with and without the target gas in the collision cell. Corrections for forward scattered positrons, which are needed for measurements made using a magnetic beam, are not necessary in this case. This beam can also be used for the investigation of solid surfaces, taking advantage of the magnetic field-free characteristic and the low divergence.

### References

- [1] Schultz P and Lynn K 1988 *Rev. Mod. Phys.* **60** 3 701.
- [2] Gidley D *et al* 1982 *Phys. Rev. Lett.* **49** 24 1779.
- [3] David A *et al* 2001 *Phys. Rev. Lett.* **87** 6 067402.
- [4] Fujinami M *et al* 2008 *Analytic. Sci. J.* **24** 73.
- [5] Nagumo K *et al* 2011 *J. Phys. Soc. Jpn.* **80** 06431.
- [6] Nagumo K *et al* 2012 *Eur. Phys. J. D* **81** 66.
- [7] Saito F *et al* 2002 *Appl. Surf. Sci* **194** 13.
- [8] Fischer D and Lynn K 1986 *Phys. Rev.* **33** 7 4479.