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ABSTRACT

Set-up for positron-molecule scattering measurements in the range of energy 0.1 – 20 eV is presented. To obtain a positron beam with suitable electron optical parameters apparatus uses brightness enhancement stage.

Keywords: Low energy positron spectrometer, brightness enhancement technique, positron moderation.

1 INTRODUCTION

Low energy scattering experiments are of basic importance for understanding atomic and molecular structure [1]. The absolute values of total cross sections for positrons in the range of energies below 1 eV allow us to set correlations between the value and shape of total cross section curve and atomic or molecular structure. Current scientific questions include the possibility of bound states of positrons with atoms and molecules, the role of vibrational excitation in the formation of long-lived positron-molecule resonances, and the fragmentation following positron annihilation [2]. The very low-energy range of low-energy positron scattering is also of interest for the investigation of Ramsauer-Townsend minima. There are only some indications for the existence of such minima in molecular gases like N_2, in contrast with the electron scattering case, see fig.1 [3]. At high energies positron and electron cross sections should merge, but this is not the case of N_2 up to 700 eV, as shown for example in fig. 1.

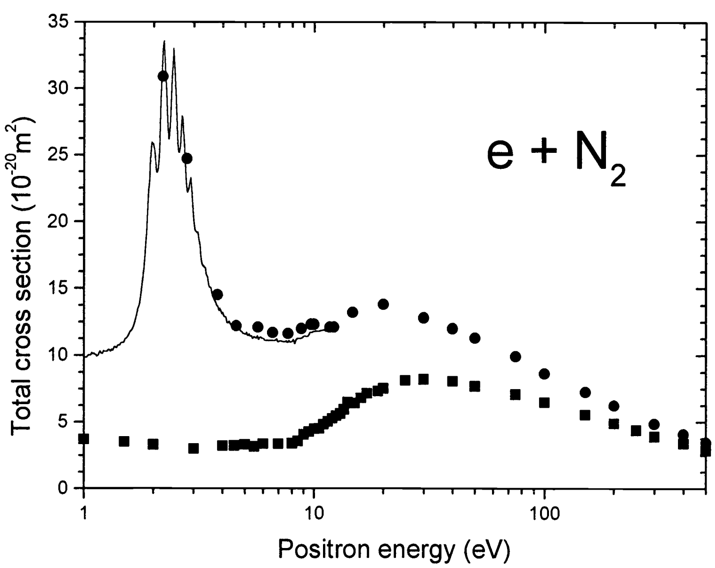

Fig.1. Total cross sections for electron (upper curves and points) and positron (lower points) scattering on N_2. Data are from Hoffman et al. [3].

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2 APPARATUS

The lay-out of the set-up is shown in fig. 2. The optical system of the apparatus consist of four major optical sections: first accelerator stage, deflector, remoderator, injection and gas cell.

The first accelerator consists of three cylindrical elements and assures the extraction of the beam from the moderator. The positron source used in experiment was the encapsulated ^{22}NaCl salt, deposited in a cage in a 8 mm tungsten cylinder and closed by a 5μm Ti window. In front of the Ti window a 1 μm W monocrystal foil was placed [4]. We have assumed the ±15° angular limit for the beam in designing this accelerator. Fig. 3. shows the ray-tracing of positron beam transport for experimentally optimised potentials.

The deflector is a 90° electrostatic spherical prism used to prevent high-energy positrons from the source reaching the target. Positrons come out from the deflector with energy of 200 eV.

The second accelerator (remoderator stage) constitutes the system of three electrostatic lenses, which transports the beam to the remoderator. The accelerator produces a demagnified spot onto the Cu foil and positrons emerge from a smaller spot with higher brightness [5]. The acceleration energy is tuneable from 2 to 6 keV. This stage works also as an electron gun, which allows in situ remoderator conditioning. The ray-tracing of Cu film heating in situ shows fig. 4.

The brightness enhancement technique was chosen to obtain a positron beam with suitable electron optical parameters [6]. With this technique a slow positron beam from a first moderator is focused at energy of a few keV onto a second moderator. The reemission process involves non-conservative forces. This fact allows to circumvent the Liouville theorem and to increase the brightness of the beam after the second moderation. In the second accelerator a pulsed beam is prepared for the scattering experiment.

The electron optics after the remoderator is extremely compact, occupying in total less than 2 cm in length. It contains an anode with a real aperture, a Soha electrode, a specially shaped pulse electrode and a focusing one. The shape of the electrodes has been designed to optimise the coupling of the high frequency gating signal. The scattering cell is 100 mm long, with entrance and exit apertures of 0.5 mm diameter. It is separated from the injection optics by a 2 cm long dummy cell, in order to improve the pumping efficiency.

In order to guide the low energy positrons, a weak longitudinal magnetic field is used, in a lens-like configuration [7]. All the optical elements after the remoderation stage are immersed in this field. The system shows monochromating features, see fig. 4, transmitting only positrons, which completed an integer number of gyrations between the entrance and exit apertures of the scattering cell.

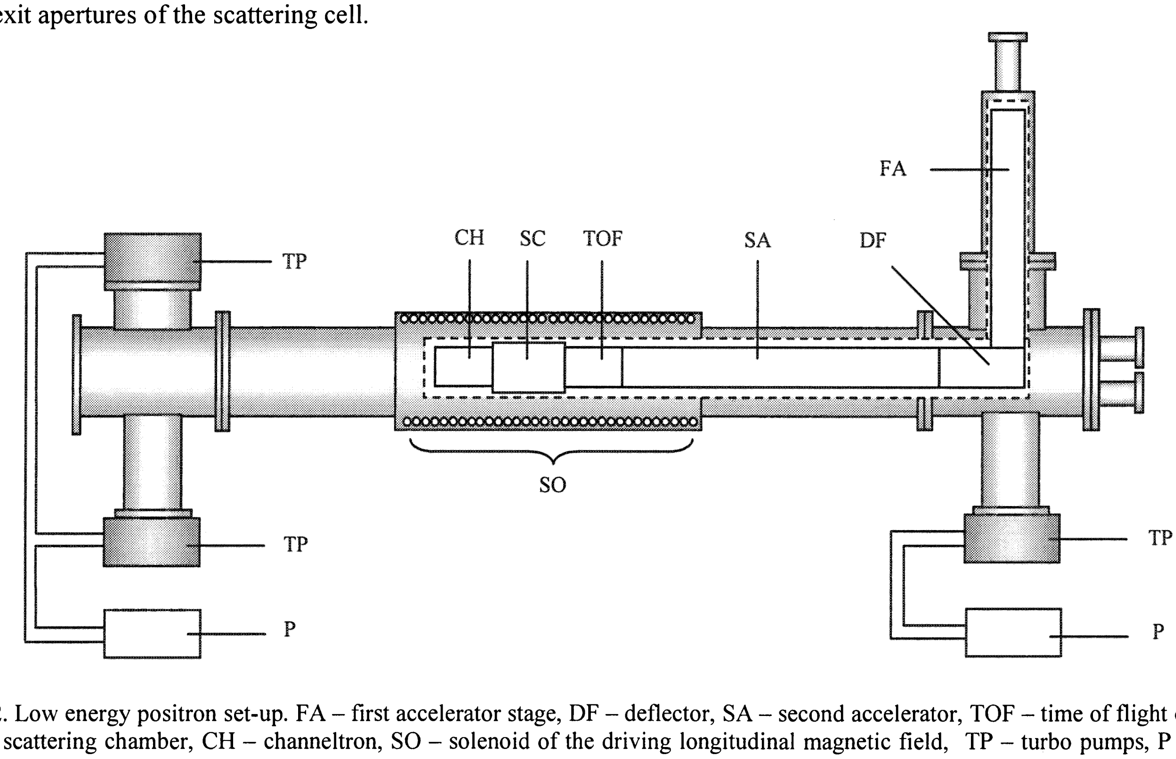

Fig. 2. Low energy positron set-up. FA – first accelerator stage, DF – deflector, SA – second accelerator, TOF – time of flight optics, SC – scattering chamber, CH – channeltron, SO – solenoid of the driving longitudinal magnetic field, TP – turbo pumps, P – pre-vacuum pumps. Length of the scattering chamber with real apertures of 0.5 mm diameter – 10 cm.

The apparatus is shielded by an external μ-metal (about 20,000 the relative magnetic permeability) box which around the secondary (i.e. after the deflector) beam. has the form of a double cylinder. The shield allows to reduce the stray magnetic fields to below $0.2\cdot10^{-7}$ T. Additionally, the Earth's field is compensated by a set of triple Helmholtz coils [8]. The apparatus is working in a vacuum down to $1.5\mathrm{x}10^{-10}$ Tr. The vacuum system is based on four turbo pumps: one 800 l/s for pumping the scattering chamber region, two 250 l/s each for the electron-optical column and for the channeltron region; one 70l/s is used to pump the first moderator conditioning chamber. All vacuum tubes and flanges are machined from AISI 316 LNR stainless steel. The entire optics of the spectrometer has been fabricated from a non-magnetic copper-nickel alloy (Arcap- France).

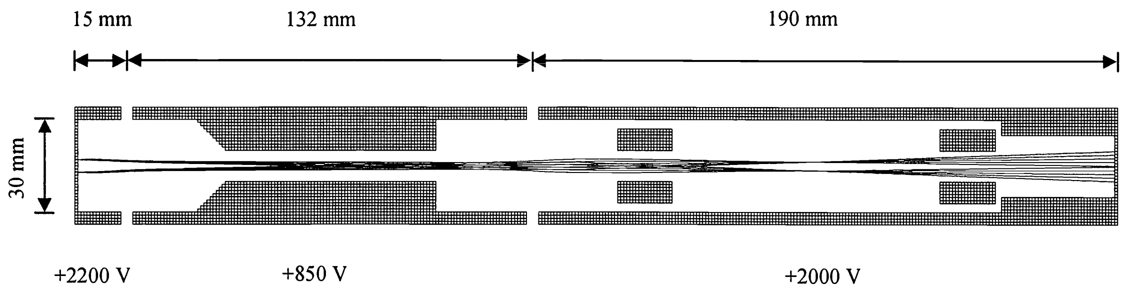

Fig. 3. First accelerator ray-tracing. Potentials on electrodes are experimentally optimised values given in volts. Angular limit for the positron beam re-simulation was defined for ±15 degrees.

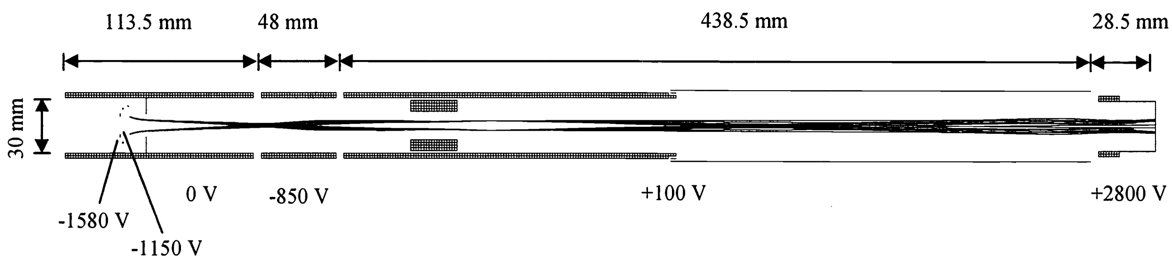

Fig. 4. Remoderator stage ray-tracing. Potentials on electrodes are the optimised conditions obtained for Cu remoderator film heating.

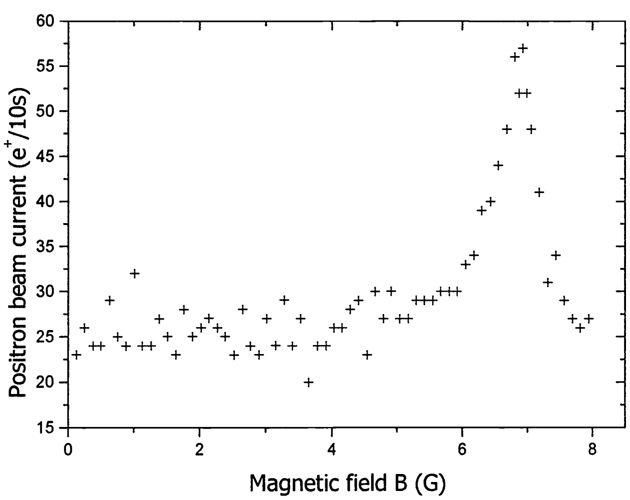

Fig. 5. Focusing of positron beam by longitudinal magnetic field.

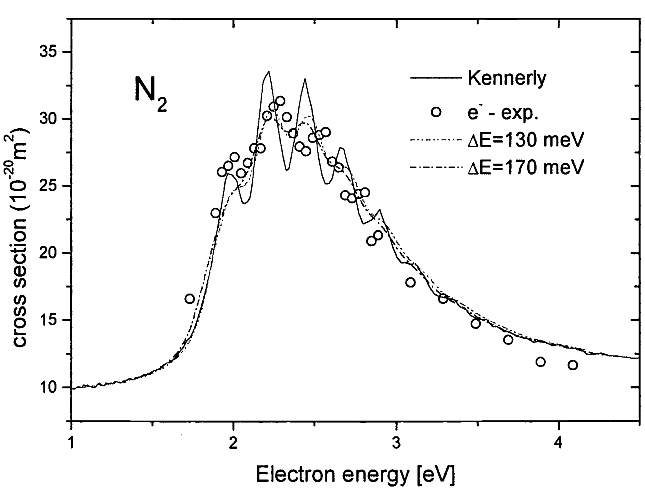

Fig. 6. Total cross sections for electron scattering on N_2: the present measurements are compared with the data of Kennerly [9].

3 RESULTS OF THE TESTS

Several tests have been completed. First, the TOF module was tested with pseudo-random pulsing [10]. The electronic circuitry proved to work correctly for electrons with 8-bit word up to 66 MHz frequency.

The injection part of the secondary beam was tested both with electrons and positrons. Contact potential for electrons proved to be depended on the temperature of thermoionic cathode used; in the final set-up secondary electrons from the moderator will be used instead of the thermoionic cathode. The apparatus was tested with electrons also for the overall energy resolution of the secondary beam. We have measured cross sections for the $^2\Pi_g$ resonant structure in N_2, see fig. 5, obtaining results in a good agreement (within 10%) with those of Kennerly [9].

Efficiency of the transmission of the secondary optics is about 75% for positrons. It was tested using a channeltron positioned in a bent configuration, outside of the optics axis, to avoid the detection of fast positrons from the radioactive source. Unfortunately, the test source was of a too big diameter and the major part of emitted positrons could not be transmitted using the designed optical parameters.

For the primary beam as many as 120 e^+/s were obtained using 1μm W moderator and the test (about 2 mCi) source. Some uncertainty on the energy resolution of the bending optics still remain.

The heating of the remoderator film with electrons emitted from a tungsten ring-like cathode positioned inside the accelerator after the bending optics was also tested. We proved that the potentials as obtained form ray-tracing, see fig.4. do not assure enough high temperature of the Cu film. This was because the space-charge limits in the cathode region. By applying higher potentials (up to 800 V) to the extraction electrode (an inverting the ratios between other potentials) we obtained as high as 800°C on Cu film.

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