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A very low-energy apparatus for positron scattering on atoms and molecules

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Abstract

An apparatus for very low-energy positron scattering measurements in gases is presented. The apparatus uses electrostatic optics, two stages of positron moderation, magnetic focusing in the scattering chamber and a pseudo-random time-of-flight correlation technique.

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A new apparatus for studies of positron scattering on gaseous targets is under construction at the University of Trento. The design aims at the measurement of positron–molecule total cross-sections in the range 0.1–20 eV. The energy range below 1 eV is practically unexplored in positron scattering, although a few measurements break this limit (see for instance [1] and references therein).

On the other side, this range is of interest for the investigation of Ramsauer–Townsend minima. At present, we have only some indications for the existence of such minima in molecular gases like N_2, in contrast with the electron scattering case, see [1]. Similarly, only pioneering measurements exist for inelastic processes, like vibrational excitations [2,3]. New solutions have been studied in the present work to design a positron beam suitable for cross-section measurements down to very low energies.

The lay-out of the apparatus is shown in Fig. 1. The brightness enhancement technique [4] was chosen to obtain a positron beam with suitable electron optical parameters. With this technique, a slow positron beam from a first moderator is focussed at an 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. Two main parts can be distinguished in the lay-out. In the first one, a positron beam is formed and focussed onto the second moderator. In the second

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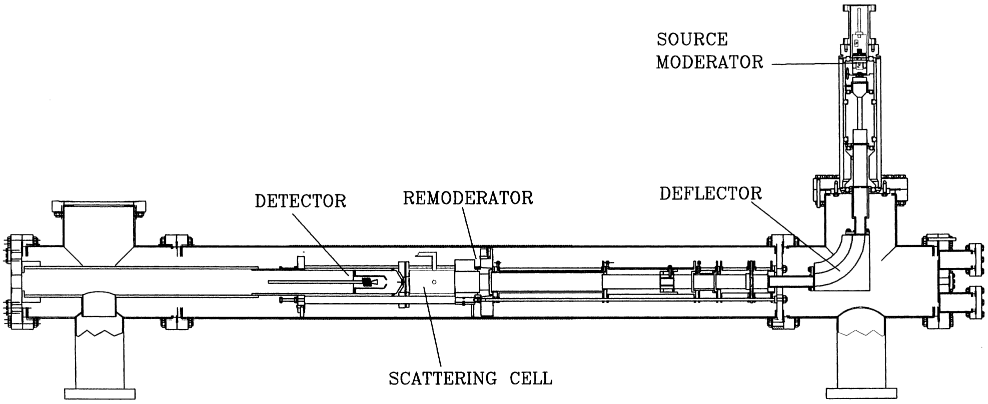

Fig. 1. Schematic drawing of the low-energy positron spectrometer.

part, a pulsed beam is prepared for the scattering experiment.

In the first part, slow positrons are produced from ^{22}Na source coupled with a W single-crystal moderator, 1 μm thick, in a transmission geometry. In the apparatus set-up, a standard 3 mm spot NaCl source is used; during the measurements, a 30-mCi source with a 2 mm spot will be used. In situ thermal annealing of the W crystal in a multistep procedure using an 8 keV electron gun assures a moderation efficiency in the 10^{-4} range [5,6]. Moderated positrons are injected by an electrostatic optics in a 90° spherical deflector. This deflector is used to prevent high-energy positrons from the source reaching the target region. The first part of the electron optics is built in W alloy, in order to improve the radiation shielding.

This first part of optics has been successfully built and used in our laboratory as a component of a positron beam for surface studies. Details on the construction, electron optical calculations and on the conditioning of the first moderator can be found in [5,6].

Positrons come out from the deflector with an energy of 200 eV. An electrostatic accelerator produces a demagnified spot onto the second moderator. The acceleration energy is tunable from 2 to 6 keV. Our remoderation stage has been chosen to work in transmission geometry with thin films. This choice has been made after weighing the advantages and disadvantages of a number of configurations, both in transmission and in back scattering. Until now only remoderated beams using bulk single crystals as remoderator in complicated back scattering geometries are in operation [7]. The electron optics for remoderation in transmission geometry is simpler; the drawback is that films of 1000 Å thickness have to be handled and heated in situ. In order to reduce the conditioning difficulties, we have separately studied the reemission properties of Cu films [8] and we have obtained a reemmision efficiency up to 12% at 6 keV impinging positron energy. These films require an annealing temperature of 600–700°C only [8]. Although we did not measure the energy spread of the remoderated positrons, we expect that it could be lower than the one of tungsten [9]. The remoderation stage allows to obtain an electron–optical source of remoderated positrons less than 1 mm diameter and consequently to reduce the size of the scattering chamber apertures. This last requirement is important for measurements below 1 eV; here some gases, like Ne or O_2, are known to exhibit very low values of total cross-sections for electron scattering [10]. We guess that similar low values can be expected for positron cross-sections. In such instances, high pressures in the scattering chamber will be needed.

The second part of the apparatus will be based on a modified time-of-flight technique, with pseudo-random correlation [11]. The use of the pseudo-random correlation instead of a standard time-of-flight pulsing will allow to obtain a duty cycle close to 50% and thus increase the number of

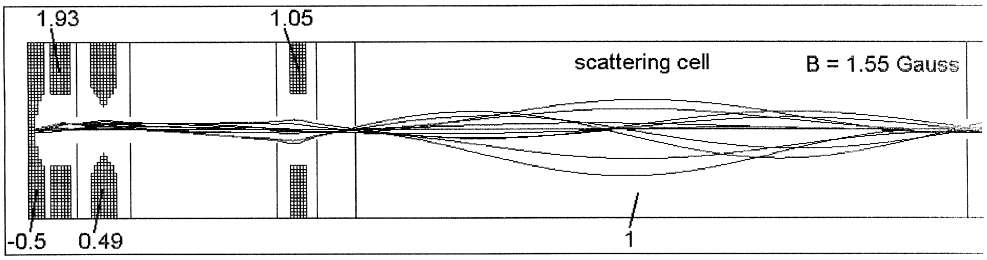

Fig. 2. Ray-tracing for a positron scattering energy of 1 eV. The voltages of the electrodes are given in *V*. The guiding magnetic field is 1.55×10^{-4} T. Hatched regions show the electrodes, real apertures are shown by vertical thin lines.

counts at the detector. The disadvantage of this technique is in a more complex analysis procedure for the measured spectra, especially in the presence of inelastic processes.

The extraction and formation electrostatic optics contains also the modulation electrode. The shape of the electrodes has been designed to optimize the coupling of the high frequency gating signal. The beam will enter a scattering cell 100 mm long, with entrance and exit apertures of 1 mm diameter. The entire spectrometer has been fabricated from a non-magnetic copper–nickel alloy.

In order to guide the low-energy positrons, a weak longitudinal magnetic field will be used, in a lens-like configuration [12]. All the optical elements after the remoderation stage will be immersed in this field. The entire apparatus is shielded by an external μ-metal box. A double cylindrical shield allows to reduce the stray magnetic fields to below 0.2×10^{-7} T. Additionally, the Earth's field is compensated by a set of triple Helmholtz coils [13].

Fig. 2 shows a typical ray-tracing for the second part of the spectrometer, from the remoderator to the scattering cell exit aperture. The ray-tracing was obtained by the SIMION program [14]. The voltages and the magnetic field value reported in this figure are related to a scattering energy of 1 eV; for clarity only one half of the trajectories are shown. The flight region works in focussing conditions [12], i.e. positrons are focussed on the interaction chamber exit aperture after completing an integer number of gyrations. We proved previously [12] in a similar set-up working at 20 eV that, under suitable conditions, a very high transmission efficiency can be achieved. The simulated spread of positron times of flight is below 1% at all energies in the planned range of operation.

The channeltron detector will be positioned close to the exit of the interaction chamber or alternatively farther downstream. This will allow to measure two distinct spectra related to the same scattering condition; work is in progress to devise how to use this additional information.

All vacuum housing is machined from AISI 316L stainless steel. Four turbo pumps are used: 800 1/s for pumping the scattering chamber region, two 250 1/s each for the electron–optical column and for the channeltron region; one 70 1/s is used to pump the first moderator conditioning chamber. A base pressure in the 10^{-8} Pa range has been achieved.

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