A Positron Accumulator for Antihydrogen Synthesis

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ABSTRACT. A positron accumulator based on the modified Penning–Malmberg design of Surko and co-workers at UCSD has been constructed and undergone testing in preparation for the ATHENA experiment now under way at CERN. This experiment aims to produce and characterize atomic anti-hydrogen. The positron accumulator utilises nitrogen buffer gas to cool and trap a continuous beam of positrons emanating from a ^{22}Na radioactive source. A solid neon moderator slows the positrons from the source down to epithermal energies of a few eV before being injected into the trap. It is estimated that around 10^7 positrons can be trapped and cooled to ambient temperature within a couple of minutes in this scheme using a 6 mCi source. Preliminary tests have so far demonstrated trapping of approximately 3 x 10^6 positrons and an efficiency of the Ne moderator of nearly 1 %.

INTRODUCTION

In order to produce low energy antihydrogen via recombination it is necessary to have copious amounts of cold positrons available. To attain this a positron accumulator based on the design of the Surko Group at the University of California San Diego [1-3] has been constructed and undergone preliminary testing in the United Kingdom before being shipped to CERN in Geneva to be a part of the ATHENA (AnTiHydrogEN Apparatus) experiment [4-5]. The accumulator is an ideal source of positrons in this case as it is capable of supplying large quantities (>10^8 in the later stages of the experiment) of positrons in short well defined bursts, with a short cycle time, in the order of 5 minutes.

EXPERIMENTAL

The positron accumulator is an instrument for trapping and cooling a continuous beam of slow positrons. A continuous beam of slow positrons injected into the accumulator is generated by moderating β+ particles from a 6 mCi ^{22}Na radioactive source and guiding them into the trapping region using a magnetic field. A cryogenic cold head capable of reaching 5.5 K cools down the source and makes it possible to grow a solid neon moderator directly on the source. The slow positrons emanating from the source/moderator are magnetically guided through a kink and a long narrow pumping restriction into the main trapping region (see [6] for details). Placing a NaI-detector close to the gate valve between the source end and the main trapping region made it possible to optimise the moderator growth. During moderator growth this gate valve would be closed and the positrons would annihilate on the closed valve. To calibrate the NaI signal to absolute beam strength a channeltron detector was briefly inserted here and coincidence measurements performed. The channeltron detector with a retarding grid in front of it was also used to measure the energy distribution of the emitted positrons.

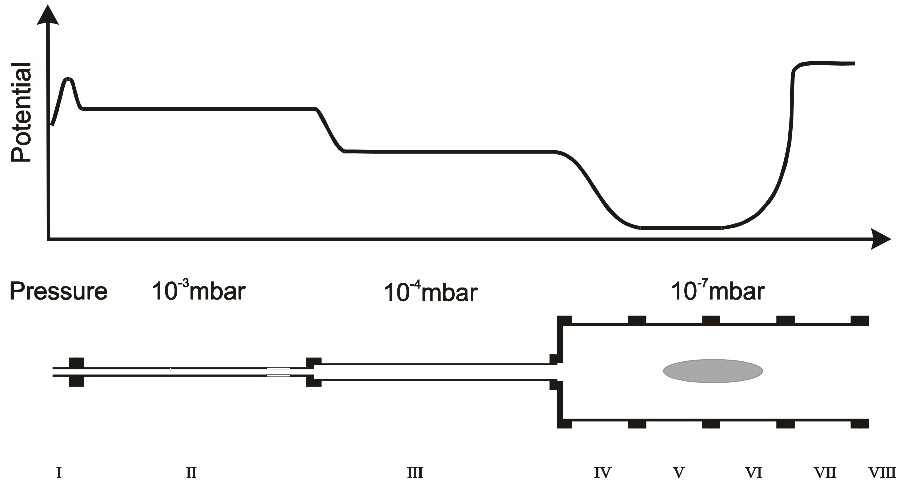

Figure 1. Schematic of the trapping scheme showing the electrode array and the pressures and electric potentials along the array.

The main trapping chamber is situated within a 0.1 T magnet and contains an electrode array. This consists of a set of eight separate gold-plated aluminium electrodes with an appropriate potential applied which will confine the positrons in the axial direction after the initial trapping (Fig.1). The 0.1 T axial magnetic field supplies the radial confinement and combined with the electric potentials this constitutes our Penning-Malmberg trap. The physical dimensions of the electrodes are designed to allow a pressure gradient to be developed along their length. Nitrogen gas can be introduced midway along electrode II and is pumped out at either end or through a set of three vents located at the end of the same electrode.

The positrons are trapped and cooled within the array via a buffer gas method. The pressure of the nitrogen gas used as buffer gas is tuned such that on average, a positron entering from the source region will experience one inelastic collision with a nitrogen molecule whilst traversing electrode II. Thus confined and unable to escape the array a second collision typically occurs within a millisecond further confining the positron to between electrodes III and VI. Typically, a third collision after some 10ms will then finally restrict the positron to electrodes IV and V.

Electrode IV is split into 6 segments, making it possible to use it to compress the plasma by applying a rotating electric field (‘rotating wall’) [7]. This method has been shown recently to work well also for positrons plasmas [8]. In our case the electrodes used have a significantly larger radius (~10 cm) than in earlier experiments but preliminary tests have shown that we can still influence the positron plasma from that distance.

The detection system used for our experiment consists of 3 detectors: (1) A segmented Faraday cup detector consisting of 9 plates to get information about the size and position of the plasma. (2) A CsI-diode detector to detect the positron annihilation signal. (3) A ‘Gauss’ Law’ signal from one of the confining electrodes caused by charge being induced on the electrode as the confined plasma is being dumped on the Faraday cup. Presently the whole experimental set-up including the data acquisition from the detectors is being automated to make it possible to run the experiment remotely.

RESULTS

A study of moderator growth was conducted using a channeltron and a NaI detector in coincidence in order to ascertain the moderator efficiencies for different moderator thicknesses etc. These detectors were placed at the entrance to the main vacuum system. Using this method we have been able to detect more than 1.6×10^{6} e+ s^{-1}, giving a moderator efficiency of 0.62 % based on a source strength of 7 mCi at the time of the measurement. However, using a measurement of the current of positrons from the source taken during an electronically quiet period as the base for the moderator efficiency a real efficiency of 0.76 % is reached. The study of the energy distribution of

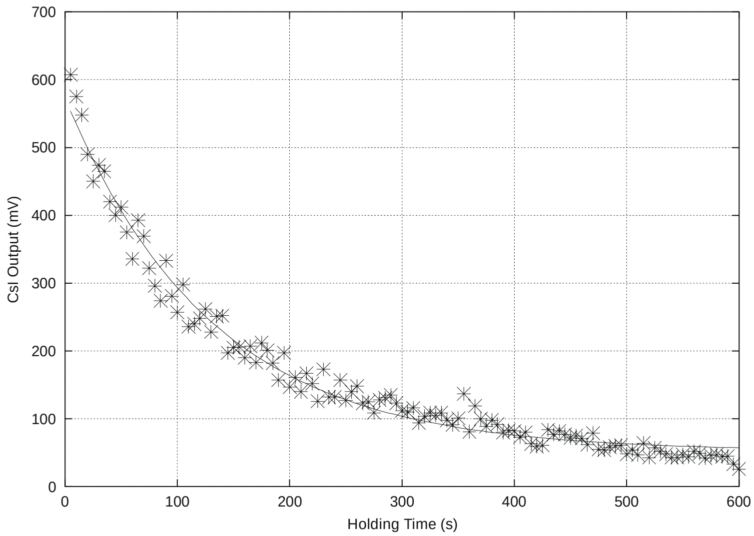

Figure 2. The annihilation signal (CsI-diode) as a function of time after accumulation had ceased and the buffer gas was pumped out. The data show a half-life for the positrons of about 100 s when the buffer gas is pumped out.

the positrons emitted from the neon moderator showed at FWHM of 2.2 eV though the centroid of the distribution appeared to be moving slightly from moderator to moderator. Generally the half-life of our moderators (the time until the beam strength drops to half its original value) was observed to be about 2 weeks.

Work on optimising the trapping process has been started. A rough optimisation of the trapping potentials and buffer gas pressure has been performed. During these measurements we have been able to trap about 3×10^6 e+ with a lifetime of about 30 s with the buffer gas present in the trap and about 100 s when the buffer gas was pumped out. The trapping efficiency is still rather low (about 6 %) compared to the trapping efficiencies reported elsewhere (see e.g. [1]). However, our system is not yet fully optimised so we expect to be able to improve this number. A realistic guess of the number of positrons it is possible to trap with the current source would be somewhere slightly above 10^7 positrons per cycle. For the later stages of the experiment a significantly bigger source is planned. Thus, assuming scalability, it should be possible to trap in excess of 10^8 positrons per cycle.

After trapping the positrons still need to be transferred to the 3 Tesla ATHENA main magnet where the antiproton capture trap and the recombination trap is situated. A special transfer section is being assembled for this purpose. This section consists of a number of transfer electrodes as well as a transfer magnet capable of pulsing from 0-1 Tesla in 20 ms and stay at 1 Tesla for 1 s. This system will be installed and undergo testing in the coming months.

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