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Low Energy Anti-Hydrogen Atoms Produced with Non-Neutral Plasmas
非中性プラズマを用いた低エネルギー反水素生成

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Since the production of low energy anti-hydrogen atoms reported in 2002, it has been of great interest to have those atoms available for physics experiments. At CERN Antiproton Decelerator, three groups are competing for the first physics result. Recently, ASACUSA-MUSASHI group made a step forward for anti-hydrogen beams by producing anti-hydrogen atoms in a magnetic field gradient (cusp field). In the course of experiments, non-neutral plasmas played crucial rolls. Here, the basic procedure for producing low energy anti-hydrogen atoms and possible experiments are reviewed.

1. Introduction

Non-neutral plasmas have been studied in great detail with Paul traps and Penning-Malmberg traps in a uniform magnetic field. Physical interests included are laser cooled strongly coupled plasmas, strongly magnetized plasmas in a high field, vortex structure formation, etc. They are also studied in complex fields like torus-type magnetic fields and magnetic mirror fields.

Here, synthesis of cold anti-hydrogen ($\bar{H}$) atoms in a cusp trap is reported [1]. Low energy $\bar{H}$ atoms were first produced in 2002 by mixing a low energy positron (e^+) plasma and antiprotons ($\bar{p}$) in a uniform magnetic field [2], which was made possible with the knowledge acquired through studies of cold non-neutral plasmas. However, those $\bar{H}$ atoms were not suitable for physics experiment. The next step was, with the magnetic moment of $\bar{H}$ atom, to confine $\bar{H}$ atoms in a minimum B field or to produce $\bar{H}$ -beams with a magnetic field gradient. ASACUSA-MUSASHI group utilizes a magnetic cusp field for the purposes [3].

2. Experiment

Figure 1 shows the experimental setup, which is composed of a unique low energy antiproton beam source named MUSASHI (which can provide 0.1~1 keV $\bar{p}$ beams [4]), a compact low energy e^+ accumulator equipped with ~1GBq ^{22}Na RI source [5], and a cusp trap, where $\bar{H}$ atoms are produced.

At first, 40 to 60 pulses of ~100 eV, 10^5 e^+ from the accumulator are injected into the cusp trap at the temperature of 15K [6]. About 4~6 x 10^6 e^+

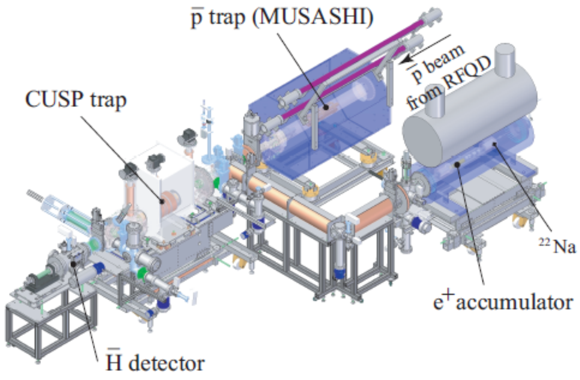

Fig.1. ASACUSA-MUSASHI experimental setup

are cooled through synchrotron radiation and a rotating electric field is applied [7] to form a cold high density e^+ plasma (with density n and temperature T). This is necessary for the higher production rate of $\overline{H}$ atoms, because it is expected that the cross sections for the three body and radiative recombinations are proportional to $n^2T^{-9/2}$ and $nT^{-1/2}$, respectively [8]. For the production of $\overline{H}$ atoms, three body recombination is thought to be the dominant process.

Meanwhile, a pulsed antiproton beam of ~5 MeV provided from AD is decelerated to ~100keV through Radio Frequency Quadrupole Decelerator, which is available only for ASACUSA, and injected into MUSASHI. Antiprotons with the energy less than ~13 keV are caught in the MUSASHI trap and a pre-loaded non-neutral electron plasma is used for the electron cooling of

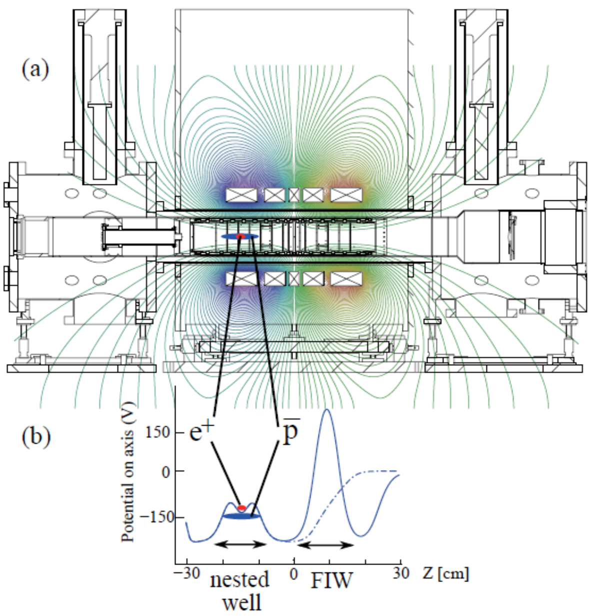

Fig.2. (a) Magnetic field lines in the cusp trap, (b) Nested potential and field ionization potential on the axis.

$\overline{p}$'s. After kicking out electrons and applying rotating electric field to $\overline{p}$'s [9], about 3 x 10^5 $\overline{p}$'s with the energy of 150 eV are injected into the e^+ plasma in the cusp trap.

Since the relative energy of injected $\overline{p}$'s against e^+ plasma is ~ 20 eV as shown in Fig.2, $\overline{p}$'s are cooled by collisions with positrons and highly excited $\overline{H}$ atoms (with the principle quantum number ~ 45) are produced. Those highly excited $\overline{H}$ atoms coming into the field ionization potential, 250 mm away from the production point, are re-ionized by the electric field and $\overline{p}$'s are trapped in the potential. The annihilation signals synchronized with the destruction of the field ionization potential is regarded as the evidence that cold $\overline{H}$ atoms are created [10].

3. Future Plan

To measure the ground state hyperfine splitting of $\overline{H}$ atom through the Stern-Gerlach type experiment, it is desirable to extract an intense ground state $\overline{H}$ atomic beam into a field free region. Thus, higher production rate of low energy $\overline{H}$ atoms is mandatory.

The new RF cavity for inducing hyperfine transition and sextapole magnet for selecting the state of $\overline{H}$ atoms will be installed for the coming physics experiment.

Acknowledgments

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