Ultra-Low Energy Antihydrogen

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The study of CPT invariance with the highest achievable precision in all particle sectors is of fundamental importance to physics. Equally important is the question of the gravitational acceleration of antimatter.

In recent years, significant progress has been achieved at the Low Energy Antiproton Ring (LEAR) at CERN in capturing antiprotons in specially designed Penning traps, in cooling them to energies of a few milli-electron volts, and storing them for hours in a small volume of space. Positrons have been accumulated in large numbers in similar traps, and low energy positron or positronium beams have been generated. Finally, steady progress has been made in trapping and cooling neutral atoms. Thus the ingredients to form antihydrogen at rest are at hand.

Once antihydrogen atoms have been formed, they can be captured in magnetic gradient traps and standard spectroscopic methods may be applied to interrogate their atomic structure with extremely high precision for comparison with the hydrogen atom. Especially, the 1S-2S transition, with a lifetime of the excited state of 122 msec and thereby a natural linewidth of 5 parts in 10^{16}, offers in principle the possibility to directly compare matter and antimatter properties at a level of 1 part in 10^{18}. Such precision can only be achieved once the antihydrogen atoms have been cooled to milli-Kelvin energies, which can be achieved with a combination of laser cooling followed by adiabatic cooling. Detailed theoretical considerations [1] point out possible advantages of studying different quantities, such as the hyperfine structure splitting of the ground state, and such studies are an important part of our program.

Following the shutdown of the LEAR facility in 1996 it was proposed by the ultra-low energy antiproton physics community, and subsequently approved by the CERN program committee, to convert the original antiproton collector ring (AC) to a dedicated decelerator to produce ultra-low energy antiprotons for the formation and study of antihydrogen and related physics questions (AD) [2]. The modifications of this facility have been completed, and first antiprotons have been delivered to the experimental areas in December of 1999. This current year will be the first year of running for three approved experiments on this machine, one of which is the ATHENA experiment (**A**ppara**T**us for **H**igh Precision **E**xperiments with **N**eutral **A**ntimatter or **A**n**T**i**H**ydrog**EN** **A**pparatus for short).

We have defined the experimental program for ATHENA in two phases. Phase I will concentrate on the formation of antihydrogen under different experimental conditions and will analyze the resulting energy distribution of the neutral atoms, an important input parameter for the design of the phase II trapping of neutral antihydrogen atoms. Using the method developed in experiment PS200 at LEAR [3] antiprotons will be captured in a half meter long, cylindrical Penning-Malmberg trap, and cooled to thermal equilibrium with the ambient temperature of the surrounding apparatus by electron cooling. The plan is to accumulate 10^7 cold antiprotons using the method of successively stacking antiproton bunches into the central well of the trap. Assuming 5 $\times 10^7$ antiprotons per pulse from the AD and a 1 % capture efficiency 20 pulses would be needed to achieve this goal.

Positrons will be accumulated in a separate trap system similar to the positron accumulator presently operated at the University of California in San Diego [4], in which 10^8 low energy positrons are routinely accumulated in a few minutes.

One of the biggest challenges consists of bringing the antiprotons and positrons in close contact for a time sufficiently long to allow the recombination process to take place. Since the low energy of the antiprotons, and hence of the antihydrogen atoms, is a mandatory requirement for trapping the antihydrogen in magnetic traps, it is necessary to start with the coldest possible constituents and chose a recombination method that adds minimal recoil energy to the formed antihydrogen.

To effectively form a bound antiproton-positron state starting from free particles, excess energy and momentum has to be carried away by a third particle. Various schemes for producing antihydrogen have been proposed and discussed in some detail in the literature (see [5]), the simplest process being spontaneous radiative recombination (SRR), possibly stimulated by laser radiation. A different approach to enhance the rate of antihydrogen formation is based on three-body recombination (TBR) using high positron densities. Both these reactions require that two plasmas of opposite charge (antiprotons and positrons) are trapped and brought into contact.

The final stage of the positron accumulator, the antiproton catching trap, and the recombination trap, together with their respective magnet systems will be housed in a single, large diameter, cryogenic bore cryostat. This will facilitate transfer of the charged plasmas between the individual trap sections and also help to achieve the extreme high vacuum required for long storage times and low background annihilation.

To detect the signature of antihydrogen production (and subsequent annihilation) the central part of the trapping system is surrounded by a detector consisting of two layers of silicon strip detectors for charged particle tracking and a barrel of CsI crystals to detect the 2-photon annihilation of the positrons. Spatial and temporal resolution of this detector have been designed to allow clear discrimination between background annihilations of antiprotons and positrons in the respective traps and the annihilation of a neutral antihydrogen atom escaping from the central region. First spectroscopy of antihydrogen will be possible using this particle detector.

Using the results from this stage we will then finalize the design of the phase II apparatus to achieve the highest obtainable precision in the direct comparison of antihydrogen and hydrogen.

[1] R. Bluhm, V. A. Kostelecky, N. Russell; Phys. Rev. Lett. **82** 2254 (1999)

[2] S. Maury; Hyperfine Interactions **109** 43 (1997)

[3] M. H. Holzscheiter, et al.; Phys. At. Nucl. **57** 1870 (1994)

[4] R. G. Greaves, M. D. Tinkle, C. M. Surko; Phys. Plasmas **1** 1439 (1997)

[5] M. H. Holzscheiter, M. Charlton; Rep. Prog. Phys. **62** 1 (1999)