Lamb shift measurement of antihydrogen for determining the charge radius of antiproton and a stringent test of CPT symmetry

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Synopsis Measurements of Lamb shift in antihydrogen atom have been planned to extract the antiproton charge radius which has never been experimentally investigated. A hyperfine spin filter and a microwave cavity can be employed.

Cold antihydrogen ($\bar{\mathrm{H}}$) atoms have been synthesized recently at CERN to test CPT symmetry and weak equivalence principle. Several groups at CERN have launched experiments of precise spectroscopy for 1S–2S transition and ground-state hyperfine transition, while the Lamb shift of $\bar{\mathrm{H}}$ atoms has not been targeted. We plan a measurement of the $2\mathrm{S}_{1/2}$–$2\mathrm{P}_{1/2}$ Lamb shift of $\bar{\mathrm{H}}$ at CERN AD-ELENA facility.

Precise spectroscopic study of the Lamb shift in $\bar{\mathrm{H}}$ will yield information on the antiproton ($\bar{p}$) size which has never been investigated experimentally. The most precise direct measurement of the Lamb shift using atomic hydrogen beams achieved 9×10^{-6}[1], which determined the charge radius of the proton at an accuracy of 3%[2]. Any CPT violation could also emerge from a discrepancy between the proton and the antiproton radii [3].

The measurement has been planned to be performed at the GBAR beamline constructing at AD-ELENA, where $\bar{p}$ beams at several keV in kinetic energy are injected into a dense positronium (Ps) target and provide neutral anti-atoms together with positively charged anti-ions by the following charge exchange reactions;

$$\begin{aligned}\bar{p}+\mathrm{Ps} &\rightarrow \bar{\mathrm{H}}+e^-,\\ \bar{\mathrm{H}}+\mathrm{Ps} &\rightarrow \bar{\mathrm{H}}^++e^-.\end{aligned}$$

Calculations (eg. [4]) predict $2S$ state $\bar{\mathrm{H}}$ atoms. The idea of beam spectroscopy of the Lamb shift is to use this flux of $2S$ $\bar{\mathrm{H}}$. From a designed beam intensity of AD-ELENA, the line center can be determined with an uncertainty of 100 ppm, which gives antiproton radius at the level of 10% in precision[5]. A microwave at a cavity induces a transition from thus obtained $2S_{1/2}$ of $\bar{\mathrm{H}}$ to short lived $2P_{1/2}$, antihydrogen atoms de-excite. Antihydrogen atoms in $2S$ metastable state are quenched at the end of a spectrometer line. The Lyman α light from the quenched anti-atom is detected by a photo detector.

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The resonance profile should be composed of hyperfine states of antihydrogen atom. Figure 1 shows the Breit-Rabi diagram for antihydrogen $2S_{1/2}$ and $2P_{1/2}$ states. If hyperfine states of $2S_{1/2}$ are sorted out, a spin polarized beam would be obtained. Thus, the line shape becomes narrow[6]. Two possible schemes are considered. One is to apply an rf to depopulate $F=1$ states to $2P_{1/2}$. The β_4 state will be selected. Another is a spin selector which applies an rf and a magnetic field to select α_1 or α_2 state. A hyperfine selector is studied for this purpose.

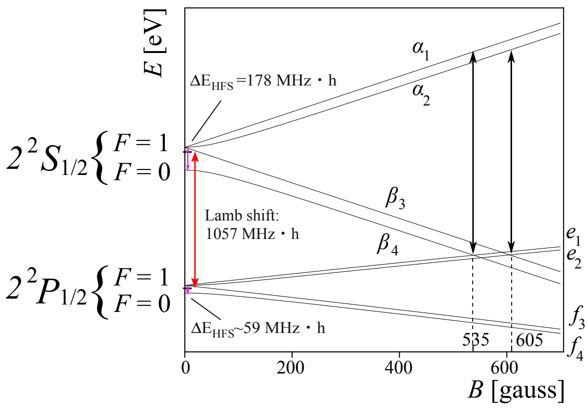

Figure 1. The Breit-Rabi diagram for $2S_{1/2}$ and $2P_{1/2}$ states of antihydrogen atom.

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