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Laser spectroscopy of long-lived antiprotonic and pionic helium atoms at CERN and PSI

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Metastable pionic helium is a three-body exotic atom composed of a helium nucleus, electron, and negatively-charged pion occupying a highly-excited state with principal and orbital angular momentum quantum numbers of n≈l-1≈17 [1,2] with a 7 ns average lifetime. We recently used the 590 MeV ring cyclotron facility of PSI to synthesize pionic helium atoms in a helium target, and induced an infrared pionic transition (n,l)=(17,16)⟶(17,15) at a resonance frequency ν=183760 GHz. This laser transition triggered an electromagnetic cascade that resulted in the π- being absorbed into the helium nucleus. By further improving the experimental precision and comparing the atomic frequencies with the results of three-body QED calculations, the pion mass may be determined to a high precision. Limits may also be established on exotic forces that arise between pions and nuclei.

In antiprototnic helium atoms, the antiproton occupies a state of n≈l-1≈38. The ASACUSA collaboration at CERN's Antiproton Decelerator facility observed an anomalous narrowing of the laser resonance lines for atoms embedded in superfluid helium so that a resolution of 2 ppm was achieved despite the fact that the atom was surrounded by a matrix of helium atoms. This may imply that exotic atoms containing kaons or other negatively-charged hadron may also be studied with a high spectral resolution [3]. We intend to improve the precision of the experiments in the future, so that quantum electrodynamics in a hadron-antihadron bound system may be studied to heretofore unprecedented precision [4,5].

[1] M. Hori, H. Aghai-Khozani, A. Sótér, A. Dax, D. Barna "Laser spectroscopy of pionic helium atoms"Nature 581, 37 (2020).

[2] M. Hori, A. Sótér, V. I. Korobov, "Proposed method for laser spectroscopy of pionic helium atoms to determine the charged-pion mass"Phys. Rev. A 89, 042515 (2014).

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[4] M. Hori et al., "Two-photon laser spectroscopy of antiprotonic helium and the antiproton-to-electron mass ratio"Nature, 475, 484 (2011).

[5] M. Hori et al., "Buffer-gas cooling of antiprotonic helium to 1.5 to 1.7 K, and antiproton-to-electron mass ratio"Science 354, 610 (2016).

In-person participation

No

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