Laser spectroscopy of antiprotonic helium embedded in liquid and superfluid helium

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Metastable antiprotonic helium is a three-body exotic atom composed of a helium nucleus, an electron in the 1S state, and an antiproton occupying a highly excited state with principal and orbital angular momentum quantum numbers of $n \approx l-1 \approx 38$ [1-5]. The atom retains a microsecond-scale average lifetime against antiproton annihilation in the helium nucleus.

We carried out laser spectroscopy of these atoms embedded in liquid and superfluid helium targets at the Antiproton Decelerator of CERN [1]. The visible-wavelength spectral lines of the atom were found to retain a sub-gigahertz linewidth in superfluid helium. This is much narrower than the optical spectral lines of many other normal-matter atoms placed in liquid helium. An abrupt reduction in the linewidth of the antiprotonic transition was observed when the liquid surrounding the atom transitioned into the superfluid phase. The hyperfine structure arising from the spin–spin interaction between the electron and antiproton was resolved with a relative spectral resolution of two parts in 10^6. No quantitative theoretical explanation for this effect has been found so far [1,3].

Metastable pionic helium [6-11] is composed of a helium nucleus, a negative pion, and an electron. We used the 590 MeV ring cyclotron facility of Paul Scherrer Institute to carry out laser spectroscopy of this atom and observed a pionic transition $(n,l)=(17,16)\rightarrow(17,15)$ having a spectral linewidth of 100 GHz [9]. The above experimental results of antiprotonic helium imply that the resolution of the pionic helium measurements may also be vastly increased. This may assist us in determining the charged pion mass with a higher precision than before [6,9,11].

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