Precision Spectroscopy of the Antiprotonic Helium Atoms.

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In recent years, ASACUSA collaboration at CERN's antiproton decelerator (AD) has made a significant progress in the precision spectroscopy of antiprotonic helium atoms ($\bar{p}\mathrm{He}^+ \equiv \mathrm{e}^- - \bar{\mathrm{p}} - \mathrm{He}^{++}$). Successive refinements in the experimental techniques improved the fractional precisions on the $\bar{p}\mathrm{He}^+$ frequencies to $\sim$ 1 part in 10^8. These included a radiofrequency quadrupole decelerator, which reduced the energy of the antiprotons from 5.3 MeV (the energy of the beam emerging from AD) to $\sim$ 100 keV. This enabled the production of $\bar{p}\mathrm{He}^+$ in ultra-low density targets, where collisional effects with other helium atoms are negligible. A continuous-wave pulse-amplified dye laser, stabilized against a femtosecond optical frequency comb, was then used to measure the $\bar{p}\mathrm{He}^+$ frequencies with ppb-scale precisions. This progress in the experimental field was matched by similar advances in computing methods for evalulating the expected transition frequencies in three-body QED calculations. Comparison of experimental (ν_{exp}) and theoretical (ν_{th}) frequencies for seven transitions in $\bar{p}^4\mathrm{He}^+$ and five in $\bar{p}^3\mathrm{He}^+$ yielded an antiproton-to-electron mass ratio of $m_{\bar{p}}/m_e = 1826.152674(5)$[1]. This agrees with the known proton-to-electron mass ratio at the level of $\sim 2 \times 10^{-9}$. The experiment also set a limit on any *CPT*-violating difference between the antiproton and proton charges and masses, $(Q_p - |Q_{\bar{p}}|)/Q_p \sim (m_p - m_{\bar{p}})/m_p < 2 \times 10^{-9}$ to a 90% confidence level. If on the other hand we assume the validity of *CPT* invariance, the $m_{\bar{p}}/m_e$ result can be taken to be equal to m_p/m_e. This can be used as an input to future adjustments of fundamental constants.

[1] M. Hori *et al.*, Phys. Rev. Lett. **96**, 243401 (2006).