Determining the antiproton-to-electron mass ratio by sub-Doppler two-photon laser spectroscopy of antiprotonic helium

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Metastable antiprotonic helium is a three-body atom consisting of a normal helium nucleus, an electron in its ground state and an antiproton occupying a Rydberg state with high principal and angular momentum quantum numbers. These atoms are amenable to precision laser spectroscopy, the results of which can in principle be used to determine the antiproton-to-electron mass ratio and to constrain the equality between the antiproton and proton charges and masses. Here we report two-photon spectroscopy of antiprotonic helium, in which the atoms are irradiated by two counter-propagating laser beams. This excites nonlinear, two-photon transitions of the antiproton at deep-ultraviolet wavelengths (139.8, 193.0 and 197.0 nm), which partly cancel the Doppler broadening of the laser resonance caused by the thermal motion of the atoms. The resulting narrow spectral lines allowed us to measure three transition frequencies with fractional precisions of 2.3–5 parts in a billion. By comparing the results with three-body quantum electrodynamics calculations, we derived an antiproton-to-electron mass ratio of 1,836.1526736(23).