学位論文 (要約)

Study of the highly excited states of antiprotonic helium atoms
(反陽子ヘリウム原子の高励起状態の研究)

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申請

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Abstract

The antiprotonic helium atom $\overline{\mathrm{p}}\mathrm{He}^+$ is a Coulomb three-body system consisting of an antiproton, an electron in the ground state, and a helium nucleus. The antiproton occupies a Rydberg state with large principal ($n \sim 38$) and orbital angular momentum ($l \sim n-1$) quantum numbers. These states are metastable, i.e., they have microsecond-scale lifetimes against antiproton annihilations. In this work, the resonance transition $(n, l) = (40, 36) \rightarrow (41, 35)$ of the antiprotonic helium isotope $\overline{\mathrm{p}}^4\mathrm{He}^+$ at a wavelength of 1154.9 nm was detected by laser spectroscopy. This transition wavelength is longer than that of any $\overline{\mathrm{p}}\mathrm{He}^+$ resonance observed so far. The purpose of detecting this transition is to obtain information about the formation process of $\overline{\mathrm{p}}\mathrm{He}^+$ in the highly excited $n \geq 40$ region. Previous experiments mostly focused on the lower-lying $n \leq 39$ states, while a small fraction of antiprotons occupying some $n = 40$ states have been detected by measuring some other laser transitions.

The present experiment was carried out by the ASACUSA (Atomic Spectroscopy and Collisions Using Slow Antiprotons) collaboration at the Antiproton Decelerator of CERN. For this experiment, we prepared a nanosecond near-infrared laser utilizing a stimulated Raman scattering process in a H_2 gas cell. The near-infrared laser generated a 7 ns long laser pulse with a wavelength of 1154.9 nm, a pulse energy of 4.5 mJ, and a diameter of 2 cm.

The population of $\overline{\mathrm{p}}^4\mathrm{He}^+$ occupying the state $(40, 36)$ was found to decay at an effective rate of 0.45 ± 0.04 $\mu\mathrm{s}^{-1}$. This value was in good agreement with the theoretical radiative rate of this state, which implies that few metastable $\overline{\mathrm{p}}^4\mathrm{He}^+$ were formed in the higher-lying states with $n \geq 41$. The number of antiprotons initially captured into the states $(40, 36)$ and $(41, 37)$ was estimated to be respectively $0.06 \pm 0.05\%$ and less than 0.02% of the total number of antiprotons stopped in a helium gas target. These values agreed with the results of previous experiments.

The experimental results were compared with the theoretical populations obtained from various calculations. These calculations have predicted that a considerable number of $\overline{\mathrm{p}}\mathrm{He}^+$ should be formed in states with $n \geq 41$. One possibility for the

apparent discrepancy between the experimental and theoretical results may be due to the fact that the populations are modified by collisions with helium atoms immediately after the formation of $\overline{p}He^+$. The formed $\overline{p}He^+$ atoms are assumed to recoil with kinetic energies of several electronvolts, and undergo a rapid thermalization, i.e., they reach a thermal temperature within picoseconds by several collisions. Some theorists have suggested that most of the highly excited $\overline{p}He^+$ atoms are destroyed by collisions during the thermalization stage.

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Appendix A

インターネット公表に関する共著者全員の同意が得られていないため、本章については、未公開

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