High-precision laser spectroscopy of antiprotonic helium atomcules and effects of collisions at high-density conditions

H.A. Torii

University of Tokyo, Physics Institute, Komaba, 3-8-1, Meguro, Tokyo 153-0041, JAPAN

The surprising metastability and the unique features of the neutral antiprotonic helium "atomcule" ($\overline{p}He^+$) has been studied extensively by the PS205 collaboration at CERN-LEAR. We have so far found 13 resonant transitions among high-n, high-l metastable states of the $\overline{p}He^+$ atomcule by the method of laser-induced annihilation spectroscopy. The observed transition energies showed excellent agreement with theoretical calculations, and thus established the level structures of this exotic atomcule.

In the course of the experiment, we observed that the central frequency of the resonances shifted and broadened with density, and systematically studied this phenomenon. High-resolution laser spectroscopy was performed in helium media of 0.2–8.0 bar at 5.8–6.3 K and 15.2 K, for two of the discovered transitions $(n, l) = (39, 35) \Rightarrow (38, 34)$ and $(37, 34) \Rightarrow (36, 33)$. We have measured the density dependence and observed linear red shifts of 0.61 ± 0.01 GHz and 0.22 ± 0.02 GHz per 1 g/ℓ, for the respective transitions at 597 nm and 470 nm. These results are qualitatively explained by a theoretical calculation based on the impact approximation with a van der Waals type collisional interaction between the atomcule and a helium atom, but certainly more elaborate theoretical work is needed for quantitative discussion.

With the shift parameters above, the transition vacuum wavelengths were extrapolated to zero-density limit, and these values were compared with recent theoretical calculations on the energy of the Coulombic three-body system, including relativistic corrections and the Lamb shift. The observed transition energies were determined to a 5×10^{-7} precision, and the agreements between our experimental values and the calculations are now as good as 2–3 $\times 10^{-6}$. This already surpasses the currently known precision (5×10^{-5}) of the $\overline{p}$ Rydberg constant, and thus we have opened a new possibility of measuring fundamental constants of the antiproton.

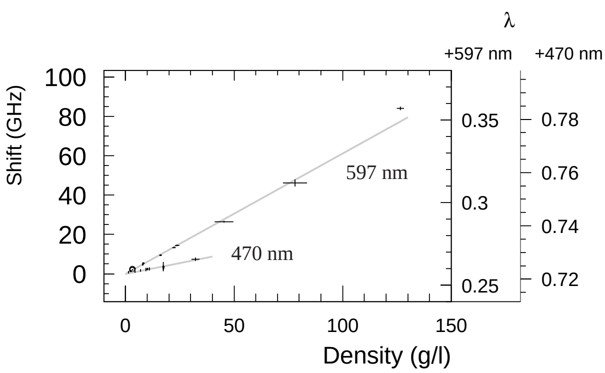

Fig.1 The central vacuum wavelength is plotted against the density of the target helium for the (n,l)=(39,35)⇒(38,34): 597 nm and (37,34)⇒(36,33): 470 nm resonance lines.

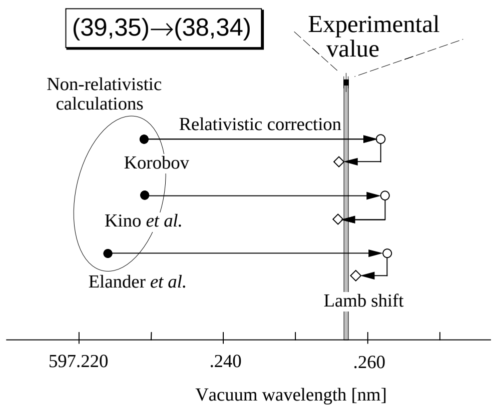

Fig.2 The experimental value of the (39,35)⇒(38,34) wavelength is compared with recent theoretical values which agree within precisions of a few ppm.