Quenching of metastable states of antiprotonic helium atoms by collisions with H_2 molecules

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Antiprotonic helium atoms are formed by Coulomb capture of antiprotons stopped in a helium target. In a series of laser spectroscopy experiments we have shown that the unusual longevity of some 3% of these exotic atoms occurs due to the formation of metastable states of the $\overline{\text{p}}$-e^--He^{2+} system [1,2]. The experimental technique used until now, however, was restricted to laser-induced transitions between metastable states (n, l), n being the principal quantum number and l the angular momentum quantum number, and adjacent nonmetastable ones $(n-1, l-1)$ at the end of each cascade with vibrational quantum number $v = n - l - 1 = \text{const}$.

Recently, we have overcome this restriction by taking advantage of state dependent quenching effects observed when H_2 is added to the helium at ppm levels. By selectively shortening the lifetimes of states with higher n, six "inverse" resonant transitions $(n, l) \to (n+1, l+1)$ between normally metastable states of antiprotonic helium atoms were observed [3]. The partial level scheme of $\overline{\text{p}}^4\text{He}^+$ shown in Fig. 1 summarizes the six "H_2-assisted inverse resonances" (HAIR) (bold arrows) and the two "conventional" transitions from a metastable (bold horizontal lines) to a short-lived level (zigzag lines) at the end of the cascades $v = 2$ and $v = 3$.

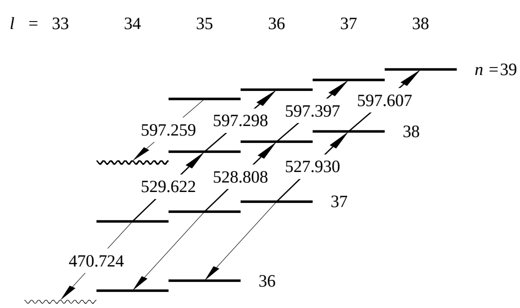

Fig. 1 Partial level scheme of the $\overline{\text{p}}\text{He}^+$ system, summarizing the six HAIR transitions between normally metastable states (bold arrows) and the two "conventional" transitions from a metastable to a short-lived state at the end of the $v = 2$ and $v = 3$ cascades (thin arrows). The experimental vacuum wavelengths for these transitions are given in units of nm.

We have employed the HAIR method to determine the decay rates of the states $(n, l) = (39, l)$, $l = 36, 37, 38$ and $(38, l)$, $l = 35, 36, 37$ of $\overline{\text{p}}\text{He}^+$ as a function of the H_2 admixture [4]. The quenching cross sections deduced for the states with $n = 39$ were found to be of the order of the geometrical cross section for $\overline{\text{p}}\text{He}^+$-$H_2$ collisions $(2 \cdot 10^{-15}\ \text{cm}^2)$, with a moderate decrease of the sensitivity to H_2 with increasing l. Within a given cascade $v = n - l - 1 = \text{const}$, the quenching cross sections for states with $n = 38$ are smaller by a factor of four to six than those for states with $n = 39$. The physico-chemical interactions leading to these strongly state dependent quenching effects are not yet understood.

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