Discovery of Hydrogen-Assisted Laser Resonance Transitions Between Metastable States of Antiprotonic Helium Atoms ◇

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The surprising longevity of a small fraction ($\sim$ 3%) of antiprotons stopped in helium has triggered a series of laser spectroscopy experiments at CERN's low energy antiproton ring (LEAR). The observation of several laser-induced resonant transitions [1] in ^{4}He and ^{3}He showed that this unusual metastability occurs due to antiprotons being captured into highly excited states of $\overline{\mathrm{p}}\mathrm{He}^+$ ($\equiv \overline{\mathrm{p}} - \mathrm{e}^- - \mathrm{He}^{2+}$) atoms with principal quantum number $n \sim n_0 \equiv \sqrt{M^*/m_\mathrm{e}} \simeq 38$ (M^* denoting the reduced mass of the $\overline{\mathrm{p}}^4\mathrm{He}^{2+}$ system and m_e the electron mass) and large angular momentum quantum number $l \lesssim n-1$.

The experimental technique used until now, however, was restricted to laser-induced transitions between metastable states and adjacent non-metastable ones, providing access only to a small fraction of states on the border between the metastable and the Auger-dominated short-lived region in the (n,l)-plane. We have now overcome this restriction by employing state-dependent quenching effects observed when small amounts of H_2 molecules are added to the helium gas [2].

Even before we started laser resonance spectroscopy on the $\overline{\mathrm{p}}\mathrm{He}^+$ system, trace amounts of foreign gases such as O_2 and H_2 in the helium gas had been found to shorten the antiproton lifetime considerably. Microscopical studies of the quenching effect using the laser resonance technique indicated that for the $v = n-l-1 = 2$ and 3 cascades states with higher n are much more strongly quenched by collisions with H_2 molecules than those with lower n. For adjacent levels in these cascades this effect leaves a higher population in the lower level than in the higher one. This population asymmetry can then be detected by a laser pulse of the corresponding wavelength, which induces an 'inverse' transition $(n,l) \rightarrow (n+1,l+1)$ between these two normally metastable states. The increased annihilation rate from the H_2-induced short-lived upper state serves as an indicator for the resonance condition. To minimize the time interval between $\overline{\mathrm{p}}$ stop and ignition of the laser we used a pulsed antiproton beam, the signal that initiated pulsed extraction being used to trigger our laser system as early as 180 ns after the $\overline{\mathrm{p}}$ arrival. The analog signal of a Čerenkov annihilation detector was recorded by a digital oscilloscope.

The most promising candidate for an 'H_2 assisted inverse resonance' (HAIR) was the transition $(38,35) \rightarrow (39,36)$ in the cascade $v = 2$, since the $(39,36)$ state was expected to be as sensitive to H_2 admixtures as the $(39,35)$ state. Scanning the laser wavelength around the value predicted by theory, a small but significant peak appeared in the analog delayed annihilation time spectrum which grew to a maximum and then decreased again, as shown in fig. 1.

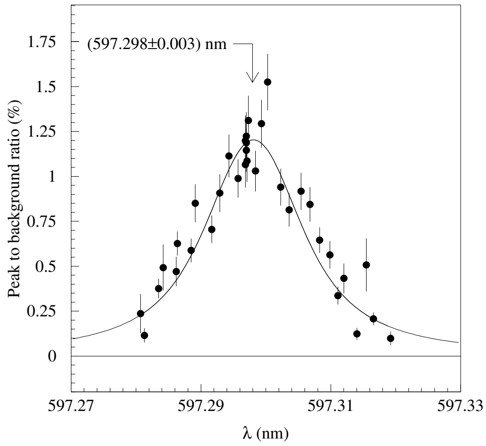

Fig. 1: Resonance profile for the transition $(38,35) \rightarrow (39,36)$.

By slightly increasing the H_2 concentration we were able to find the transitions $(38,36) \rightarrow (39,37)$ and $(38,37) \rightarrow (39,38)$, and, by adding roughly an order of magnitude more H_2 molecules, we also succeeded to identify the transitions $(37,l) \rightarrow (38,l+1)$, $l = 34, 35, 36$, as laser peaks. The central wavelengths for all the six transitions observed by the new HAIR method are presented in Table 1, where the errors cover both the statistical error and the calibration uncertainty for the wavelength meter. For comparison, results of calculations [3] including relativistic corrections are also shown.

Table 1: Experimental transition wavelengths vs. theoretical predictions.

$(n_i,l_i) \rightarrow (n_f,l_f)$	v	λ_{exp} [nm]	λ_{theo} [nm]
$(38,35) \rightarrow (39,36)$	2	597.298(3)	597.298
$(38,36) \rightarrow (39,37)$	1	597.398(3)	597.398
$(38,37) \rightarrow (39,38)$	0	597.607(3)	597.609
$(37,34) \rightarrow (38,35)$	2	529.620(15)	529.622
$(37,35) \rightarrow (38,36)$	1	528.810(15)	528.808
$(37,36) \rightarrow (38,37)$	0	527.930(3)	527.931

References

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