Laser Induced Annihilation Spectroscopy of Metastable Antiprotonic Helium Atoms

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Metastable antiprotonic helium atoms are formed when an antiproton is captured into a state with large principal and angular momentum quantum number (n, l) in the three-body Coulomb system $\overline{\mathrm{p}}$-He$^+$= $\overline{\mathrm{p}}\alpha\mathrm{e}^-$. These states can be resonantly deexcited to short-lived Auger-dominated states by irradiation with laser light, resulting in immediate annihilation of the $\overline{\mathrm{p}}$ with the helium nucleus.

The first observation of such laser induced quenching was the discovery of the transition $(n, l) = (39, 35) \rightarrow (38, 34)$ at a vacuum wavelength of 597.259(2) nm in 1993 [1]. In the following years a series of experiments was performed, in which the formation and deexcitation of exotic atoms was studied with the precision of laser spectroscopy. After a second transition in ^{4}He $[(n, l) = (37, 34) \rightarrow (36, 33)]$ had been found at a vacuum wavelength of 470.724(2) nm [2], we succeeded to stimulate transitions in ^{3}He in 1995. The observed resonances at wavelengths of 593.388(1) nm and 463.947(2) nm have been respectively assigned to the $(n, l) = (38, 34) \rightarrow (37, 33)$ and the $(36, 33) \rightarrow (35, 32)$ transitions, showing excellent agreement to the level of 50 ppm with recent theoretical predictions. The transition $(n, l) = (38, 35) \rightarrow (37, 34)$ between two metastable states in ^{4}He was found by a double resonance method, where two lasers tuned at different wavelengths induce a three-level cascade (metastable → metastable → short-lived) of the $\overline{\mathrm{p}}$. By varying the time delay of the laser pulses the lifetimes and initial populations of the respective levels have been determined.

The laser resonance method also opened the possibility to microscopically study the interactions of $\overline{\mathrm{p}}$He$^+$ atoms with neighbouring helium atoms or foreign molecules. Figure 1 summarizes the effect of target pressure (density) and admixture of a small amount of H_2 on the lifetimes of two particular levels, namely $(n, l) = (39, 35)$ and $(37, 34)$. Surprisingly, a higher target density considerably shortens the lifetime of the $(37, 34)$ state while the $(39, 35)$ state is rather insensitive to density variations. On the other hand, already a 10 ppm admixture of H_2 molecules to the helium target gas remarkably lowers the lifetime of $(39, 35)$ while the $(37, 34)$ level is more stable against quenching by hydrogen impurities.

Using a fast extracted pulsed antiproton beam from LEAR two unfavoured transitions $(n, l) \rightarrow (n + 1, l - 1)$ with a very small dipole moment have been observed for the first time. These transitions are expected to have a large hyperfine splitting due to the interaction of the electron spin with the magnetic moment of the antiproton. As this splitting can only be marginally resolved with our present dye lasers we will attempt to directly determine the level splitting of the $(37, 35)$ state via microwave resonance in 1996.

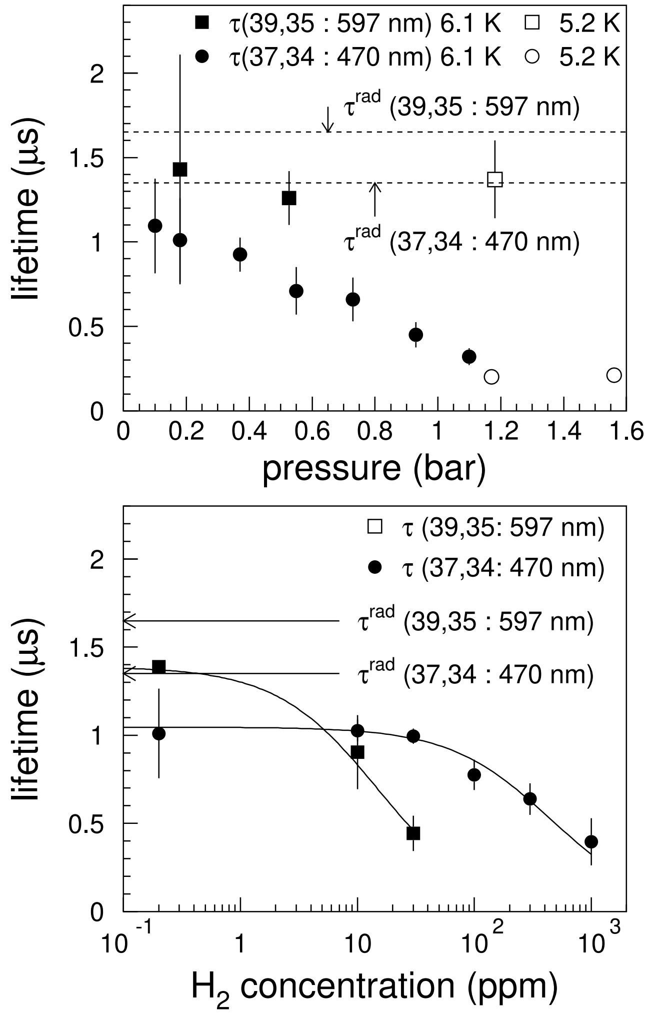

Fig. 1: Summary of density and H_2 effects on the level lifetimes of the $(39, 35)$ and $(37, 34)$ states.

References

[1] N. Morita et al., Phys.Rev. Lett. **72** (1994) 1180
[2] R.S. Hayano et al., Phys. Rev. Lett. **73** (1994) 1485; **73** (1994) 3181 *Erratum*