Oxygen and Hydrogen Quenching of Metastable Antiprotonic Helium ◇

R. Pohl, F. J. Hartmann, B. Ketzer, C. Maierl, T. v. Egidy, J. Eades [a], E. Widmann [a], T. Yamazaki [a], M. Kumakura [b], N. Morita [b], R.S. Hayano [c], M. Hori [c], T. Ishikawa [c], H. A. Torii [c], I. Sugai [d], and D. Horváth [e]

[a] CERN, CH-1211 Geneva 23, Switzerland
[b] Institute for Molecular Science, Myodaiji, Okazaki 444, Japan
[c] Department of Physics, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113, Japan
[d] Institute for Nuclear Study, University of Tokyo, 3-2-1 Midori-cho, Tanashi, Tokyo 188, Japan
[e] KFKI Research Institute for Particle and Nuclear Physics, H-1525 Budapest, Hungary

The lifetime of metastable antiprotonic helium atoms can be considerably shortened by tiny amounts of foreign gases such as H_2, N_2, O_2 and others including noble gases. However, our experiments performed at CERN's LEAR facility showed that quenching mechanisms and cross-sections differ very much between different gases [1], even between diatomic molecules like H_2 and O_2. Microscopic understanding of the involved effects is still incomplete.

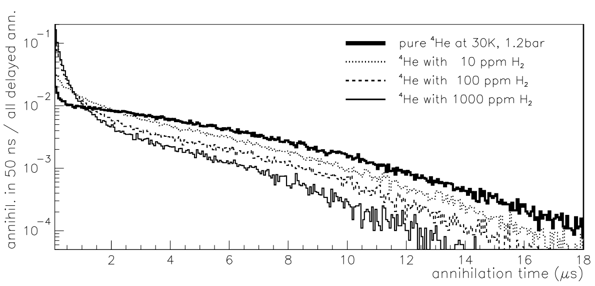

Fig. 1: DATS of $\overline{\mathrm{p}}\mathrm{He}^+$ with and without H_2 admixtures

A **D**elayed **A**nnihilation **T**ime **S**pectrum (DATS) results from the superposition of nearly independent parallel cascades with $v = n - l - 1 = const$ $(n \approx 38, l \lesssim n-1)$ which are known to exist in $\overline{\mathrm{p}}\mathrm{He}^+$. Although DATS do not reveal information about individual cascades, they do provide some information about the quenching by impurities. Fig. 1 shows some DATS with H_2 admixtures.

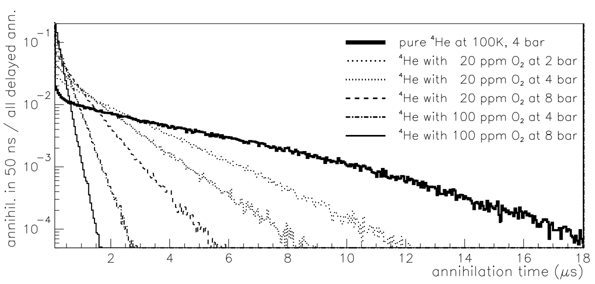

Fig. 2: DATS of $\overline{\mathrm{p}}\mathrm{He}^+$ with and without O_2 admixtures

The increase of the fast component (below 2μs) indicates a selective quenching of some metastable levels while the persistence of the long-lived part and its downward-bent shape is explained by other levels remaining unaffected. Laser experiments show that hydrogen quenches levels with larger principal quantum number n much stronger than those with smaller n [2], thus enabling the so-called 'hydrogen-assisted-inverse-resonance' method [3,4].

A different behaviour is seen when we add small amounts of oxygen to the helium gas, cf. fig. 2. Oxygen quenches antiprotonic helium much stronger than hydrogen and already at very low oxygen number densities the DATS shape becomes nearly single-exponential. The latter indicates a similar quenching effect for all metastable levels and simulations have shown that in this case the slope of the DATS corresponds to the quenching rate. A fit of a four-level cascade model to the data gives an individual level quenching cross-section in the order of $10^{-15}\mathrm{cm}^2$.

We also performed a series of laser experiments to examine the time evolution of the populations of the two already well-known levels $(n, l) = (37, 34)$ [5,6] and $(39, 35)$ [7]. Laser-induced resonant deexcitation causes a peak in the DATS, with an area proportional to the level population at that instant.

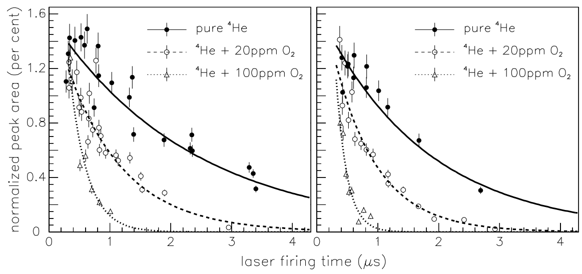

Fig. 3: Laser timing scans of the $(37, 34)$ (left) and the $(39, 35)$ (right) level for different O_2-admixtures at 100K, 4bar. The lines represent a fit of a single-exponential decay to the data points

An 'overall cascade lifetime' can be obtained by varying the laser firing time and assuming a single-exponential population decrease as a first order approximation to the sum of several exponentials, which is the exact solution of the multiple rate equations [1]. Fig. 3 shows this for the upper $(39, 35)$ and lower $(37, 34)$ level. The fact that both populations survive O_2 admixtures to nearly the same number density suggests similar quenching cross-sections for both levels. The quenching cross-sections extracted from the simple single-exponential fit to the time scans seen in fig. 3 agree quite well with the value of $10^{-15}\mathrm{cm}^2$ obtained from the DATS analysis.

References

[1] E. Widmann et al., Phys. Rev. **A53** (1996) 3129
[2] B. Ketzer et al., Jahresbericht 1995, p. 57
[3] B. Ketzer et al., Phys. Rev. Lett. **78** (1997) 1671
[4] B. Ketzer et al., this report, p. 51
[5] N. Morita et al., Phys. Rev. Lett. **72** (1994) 1180
[6] R. S. Hayano et al., Phys. Rev. Lett. **73** (1994) 1485; Phys. Rev. Lett. **73** (1994) 3181 (E)
[7] F. E. Maas et al., Phys. Rev. **A52** (1995) 4266

◇ Supported by the BMBF