Quenching of Metastable States of Antiprotonic Helium by Hydrogen and Deuterium Molecules ◇

B. Ketzer, F. J. Hartmann, T. v. Egidy, C. Maierl, R. Pohl, 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

Antiprotons stopped in ordinary matter are captured by the Coulomb force into an atomic orbit around the nucleus of a target atom, thereby liberating one of its electrons. This newly formed exotic atom is expected to disintegrate within a few ps due to the annihilation of the antiproton with its nucleus. An exception to this rule was found in helium, where a small fraction of antiprotons was observed to survive as long as several μs. In a series of laser spectroscopy experiments on antiprotonic helium [1] we have shown that this unusual longevity is due to the formation of a metastable class of these exotic atoms with principal quantum number $n \approx 38$ and large orbital quantum number $l \lesssim n-1$. The highly excited states occupied by members of this class predominantly decay via a cascade of slow radiative transitions with $\Delta l = \Delta n = 1$ or, equivalently, with constant vibrational quantum number $v = n - l - 1$.

While these long-lived states were found to be very stable against collisions with surrounding helium atoms, they turned out to be efficiently depopulated by collisions with such molecules as hydrogen and oxygen. Laser spectroscopic measurements of the lifetimes of eight metastable states as a function of the admixture ratio of H_2 molecules yielded state-dependent quenching cross sections which were found to increase strongly for energetically higher-lying states within a given cascade. For increasing orbital quantum number a moderate decrease was observed [2].

In order to shed some new light on the physics of the underlying quenching processes, it was obvious to investigate the influence of the different vibrational and rotational level structure of deuterium molecules on the quenching efficiency. A comparison of delayed annihilation time spectra with admixtures of H_2 and D_2 molecules suggested a similar state-dependent effect for D_2, but allowed no conclusions to be drawn concerning individual states. By inducing laser transitions between a metastable and an adjacent short-lived level at the end of a given cascade, the lifetime τ of the resonantly deexcited state can be measured directly. Its feeding from higher-lying states can be studied by varying the laser firing time with respect to the arrival of the antiproton, yielding an "overall cascade lifetime" T_v. The inverse cascade lifetime, $(T_v)^{-1}$, can be interpreted as the decay rate $\gamma = \tau^{-1}$ of the last metastable state, provided that replenishing of the state emptied by the laser is negligible, as was indeed observed for sufficiently high number densities of H_2 and D_2 molecules. Figure 1 compares the decay rates of the levels $(37,34)$ and $(39,35)$, measured at various H_2 and D_2 admixture ratios.

◇ Supported by BMBF

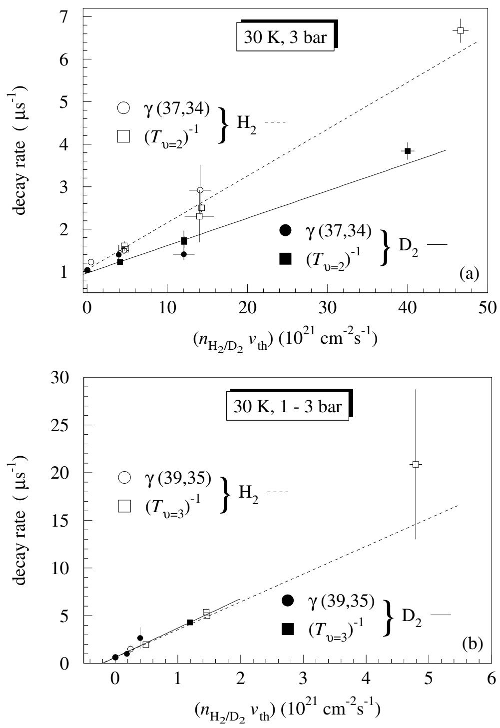

Fig. 1: Decay rates of the levels (a) $(37,34)$ and (b) $(39,35)$ for different H_2 and D_2 admixture ratios, respectively.

By fitting the sum of the decay rate in pure helium and the quenching rate, $\gamma(n,l) = \gamma_0(n,l) + n_{H_2/D_2}\, v_{th}\, \sigma_q(n,l)$, to the data, the quenching cross sections presented in Table 1 were deduced.

(n,l)	$\sigma_q^{H_2}$ $(10^{-16}\,cm^2)$	$\sigma_q^{D_2}$ $(10^{-16}\,cm^2)$
$(39,35)$	29.2(11)	30.8(14)
$(37,34)$	1.10(5)	0.65(5)

Table 1: Quenching cross sections σ_q in units of $10^{-16}\,cm^2$.

While the level $(39,35)$ is equally quenched by both isotopes, the lower-lying state $(37,34)$ is somewhat less affected by D_2 than by H_2 molecules, suggesting that the state dependence of the quenching is even more pronounced in the case of D_2 admixtures.

References

[1] N. Morita *et al.*, Phys. Rev. Lett. **72** (1994) 1180
[2] B. Ketzer *et al.*, J. Chem. Phys. **109** (1998) 424