Collisional Stark Transitions and Induced Annihilation of Cold Antiprotonic Helium Ions

G.Ya. Korenman and S.N. Yudin
Institute of Nuclear Physics, Moscow State University

In the recent experiment [1] long-lived antiprotonic helium ions ($\bar{p}\,^4\mathrm{He}^{++}$) and ($\bar{p}\,^3\mathrm{He}^{++}$) in the high circular states were observed for the first time. The data were obtained at the densities $\rho = (0.3 \div 20) \cdot 10^{17}\,\mathrm{cm}^{-3}$ of the cold targets ($T \sim 10$ K). The measured values are decay rates of annihilation signals *vs.* target density, $\gamma_n(\rho)$, for the circular orbits ($l = n-1$) with $n = 28$, $30 \div 32$ in ^{4}He and $n = 28 \div 31$ in ^{3}He. The observed values of isotope effect, n-dependence of the per-atom rates $d\gamma_n/d\rho$, as well as large values of the rates $\gamma_n(\rho)$, occur unexpected and pose interesting theoretical problems. A full theoretical description of the data has to consider some multistep cascade transitions of the antiprotonic helium ion in the medium, including collisional Stark transitions, induced and spontaneous annihilation, external Auger process, radiative transitions *etc.*

In this paper we consider collisional Stark transitions and induced annihilation of antiproton in the high states ($n \sim 30$) of antiprotonic helium ion,

$$(\bar{p}\mathrm{He}^{+2})_{nl} + \mathrm{He} \to \begin{cases} (\bar{p}\mathrm{He}^{+2})_{nl'} + \mathrm{He} \quad (\mathrm{Stark}), \\ \pi \ldots \pi + X \quad (\mathrm{annihilation}) \end{cases} \tag{1}$$

The processes at very low energy (~ 10 K) are considered in the framework of quantum coupled-channels method taking into account all the states with different l at given n (~ 30). Elastic scattering, Stark transitions and induced annihilation during collisions are produced by scalar and dipole terms in the interaction. It is shown that the most important contribution to the processes comes from the long-range polarization interaction. Admixtures of the s- and p-states to the states with higher l during collisions induce the effective annihilation cross sections for the initial l up to 15, but don't affect the Stark cross sections for the initial states nearly to circular orbits. Total rates of the Stark transitions from the circular orbits with $n = 28 \div 32$, averaged over the thermal motion, are compatible with the ASACUSA data. The dependence on n as well as isotope effect are also qualitatively agree with the experiment.

---

[1] M. Hori, J. Eades, R.S. Hayano, et al. Phys. Rev. Letters **94**, 063401 (2005).