# Low-energy collisions of excited positronium with antiprotons

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**Synopsis** We investigate $l$-mixing and charge transfer processes in positronium-antiproton collisions using the convergent close coupling method and the threshold theory. We find substantial differences with the results of classical trajectory Monte Carlo simulations.

Collisions of excited positronium (Ps) atoms with antiprotons is an efficient way of producing antihydrogen atoms in the reaction [1]

$$\mathrm{Ps}(n_i,l_i)+\bar{p}\rightarrow\bar{\mathrm{H}}(n',l')+e^-. \qquad (1)$$

Relevant processes important for understanding of the antihydrogen formation are elastic and inelastic collisions

$$\mathrm{Ps}(n_i,l_i)+\bar{p}\rightarrow\mathrm{Ps}(n_f,l_f)+\bar{p}. \qquad (2)$$

$l$-mixing collisions with $n_i=n_f$ can be called quasielastic because of the degeneracy of Ps states in $l$ for a given $n_i$.

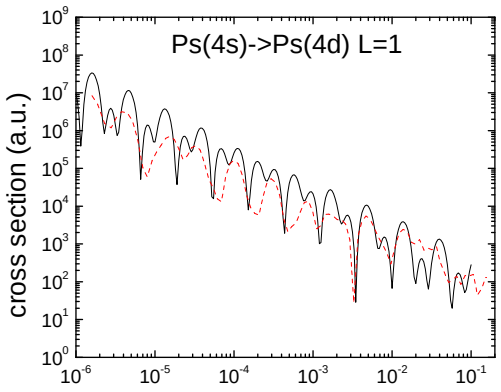


**Figure 1**. Partial cross section for $\mathrm{Ps}(4s)\rightarrow\mathrm{Ps}(4d)$ transition due to collisions with $\bar{p}$. Solid line: threshold theory. Dashed line: CCC calculations.

In the present work we extend our previous studies of $\mathrm{Ps}(n_il)-\bar{p}$ collisions [2] to $n_i\geq 3$. First we compare the results of the threshold theory (TT) [3] with the convergent close coupling calculations (CCC). The TT predicts oscillations of partial $l$-mixing cross sections as functions of $\ln(E)$ where $E$ is the collision energy. With the growth of $n_i$ these oscillations become more irregular due to contribution of several harmonics to the cross section. As an example, in Fig. 1 we present cross section for $\mathrm{Ps}(4s)\rightarrow\mathrm{Ps}(4d)$ transition for the total angular momentum quantum number $L=1$. Note that the phase of each harmonic cannot be determined from the TT, therefore the phases were chosen arbitrarily without attempts to fit the CCC results. It is clear though from these and similar results for other partial waves that generally the TT reproduces structure of the *ab initio* cross sections and their values averaged over oscillations.

Until recently most calculations of the processes (1), (2) were accomplished by using the Classical Trajectories Monte Carlo (CTMC) method (see, for example, [4]). To analyze their validity, we compare the results of quantum and classical [5] theories for $l$-mixing processes. We find that the quantum partial cross sections cover a much broader range of impact parameters (or collisional angular momenta) which makes the total quantum $l$-mixing cross sections substantially higher than classical. With regard to the charge transfer process (1) we observe an opposite trend due to the phenomenon of quantum suppression. As a result, the quantum charge transfer cross section grows much slower with the initial principal quantum number $n_i$ than the classical. At lower $n_i$ we do not observe a substantial growth at all, and for higher $n_i$ the cross section grows as $n_i^2$ whereas CTMC calculations predict the $n_i^4$ growth.

## References

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