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Enhancement of antihydrogen formation in antiproton collisions with excited-state positronium

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Synopsis Antihydrogen formation in positronium scattering on antiprotons is investigated using the two-centre convergent close-coupling method. A several orders of magnitude enhancement in the formation of antihydrogen is found when positronium is in an excited state. The effect is greatest at the lowest energies considered which encompass those achievable in experiment. This suggests a practical approach to creating neutral antimatter for testing its interaction with gravity and for spectroscopic measurements.

Interactions of antiprotons with positronium can lead to antihydrogen formation via the reaction $\bar{p} + \mathrm{Ps}(nl) \to \bar{\mathrm{H}}(n'l') + e^-$. This process has been investigated by Humberston *et al* [1] for $\mathrm{Ps}(n = 1)$ using the variational method. The study was limited to $\bar{\mathrm{H}}$ formation in the 1s state ($n' = 1$). There are few calculations involving $\mathrm{Ps}(n > 1)$, and none as far as we are aware extend to low energies of practical interest for the current AEgIS and GBAR experiments [2]. Calculations in the unitarised Born approximation (UBA) [3] included $\mathrm{Ps}(n \leq 4)$ initial states and extended to within 0.1 eV of threshold. However, such approximations are high-energy ones and, therefore, they cannot yield accurate results at such low energies.

We addressed the problem using the two-centre convergent close-coupling (CCC) method [4] and included all initial states with $n \leq 3$. The total wavefunction was expanded in both the atomic and positronium pseudostates with the resulting close-coupling equations solved in momentum space as coupled Lippmann-Schwinger equations. The pseudostates were generated by diagonalising the atomic and positronium Hamiltonians using the orthogonal Laguerre basis. We performed calculations with increasing basis size until the results converged to within $\pm 5\%$ at most energies. Such calculations have a total of 68 states, 34 for each center. The cross sections are obtained for $\mathrm{Ps}(nl)$ transitions to all open $\bar{\mathrm{H}}(n'l')$ states. We add the $\bar{\mathrm{H}}$-formation cross sections over $n'l'$, and present them for the summed over l Ps initial states. The results are shown in figure 1.

For the lowest energies presented we see several orders of magnitude cross section increase in going from $\mathrm{Ps}(n = 1)$ to $\mathrm{Ps}(n = 2)$ initial states. A further order of magnitude increase is obtained by starting with $\mathrm{Ps}(n = 3)$. This indicates that antihydrogen creation via interaction of Ps in excited states with slow antiprotons is a very practical proposition. More details and more results will be presented at the conference.

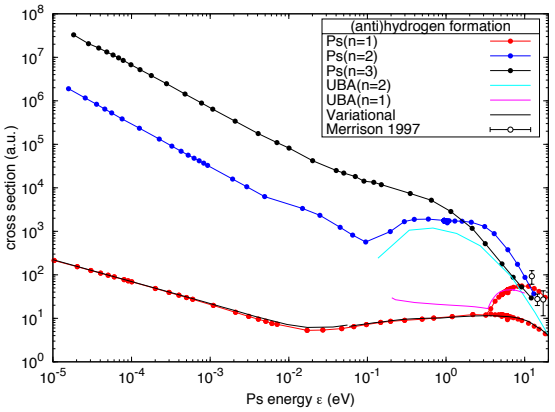

Figure 1. Total cross sections for $\bar{\mathrm{H}}$ formation in $\bar{p}$ collisions with Ps, in an initial state n, calculated using the CCC method. For Ps(1s), the variational calculations [1] are for $\bar{\mathrm{H}}$ formation in the 1s state only (corresponding CCC results are shown by unconnected points), while the UBA [3] and the CCC calculations are for $\bar{\mathrm{H}}$ formation in all open states. The experimental points are for H formation in p collisions with Ps [5].

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