Nuclear Instruments and Methods in Physics Research B 192 (2002) 42–43

NIM B
Beam Interactions with Materials & Atoms

www.elsevier.com/locate/nimb

# Antihydrogen formation in collisions of antiprotons with positronium: The effects of a strong laser field ☆

R.J. Whitehead [a], J.F. McCann [b], Y. Teranishi [c], I. Shimamura [c,*]

[a] Department of Physics, University of Durham, Durham DH1 3LE, UK
[b] Department of Applied Mathematics, Queen's University, Belfast BT7 1NN, UK
[c] Institute of Physical and Chemical Research (RIKEN), Wako, Saitama 351-0198, Japan

High-precision spectroscopy of cold antihydrogen $\overline{\mathrm{H}}$ promises to yield information on fundamental principles of physics including parity violation. A great deal of attention is focused on schemes to yield antihydrogen efficiently [1] in order to pursue this goal. On a broader front, the interactions of antiprotons $\overline{p}$ with atoms or molecules is of great interest in problems such as the formation and decay of antiprotonic matter. Here we study a three-body formation of $\overline{\mathrm{H}}$ through reactive collisions of $\overline{p}$ with positronium $\mathrm{Ps} = (e^+, e^-)$. The effect of the presence of a laser field on this process, $\overline{p} + \mathrm{Ps} \rightarrow \overline{\mathrm{H}} + e^-$, is analyzed. The process was studied over a wide range of collision energies and for a selected number of laser polarizations, frequencies and intensities.

The process is simulated by the classical-trajectory Monte Carlo (CTMC) method, which was introduced into atomic physics by Abrines and Percival [2] to calculate capture and ionization cross sections for proton–hydrogen collisions. Applications to the formation of exotic atoms have been reviewed by Cohen [3]. The CTMC method is relatively simple to execute for three-body dynamics including the effects of all possible classically accessible channels. It generally provides reasonable estimates for collision cross-sections.

The presence of an external sinusoidal field introduced by a laser was found to enhance $\overline{\mathrm{H}}$ formation. For example, an increase of 10–70% is found for light of intensity $1.4 \times 10^{13}\ \mathrm{W\,cm^{-2}}$ and wavelength $\lambda = 248$ nm for a $\overline{p}$ collision energy of 1 keV. The increases can be attributed to laser-induced target excitations. In the synthesis of $\overline{\mathrm{H}}$, based on collisional rearrangement, a laser field could act as a useful accelerant.

However, the CTMC calculation uses a classical model for the true quantum mechanical system and thus has shortcomings. Although the present CTMC results are promising, a more authoritative statement on the viability of such schemes would require quantal modeling of low-energy laser-assisted $\overline{p}$ capture by Ps, or equivalently, laser-assisted $e^+$-atom scattering leading to the formation of Ps. Extensive studies of field-free collisions of slow antiprotons with excited positronium would also be of interest.

Details of this work have been reported recently [4,5].

☆ This work has been recently published elsewhere. Please consult [4,5].

* Corresponding author.
*E-mail address:* shimamur@rarfaxp.riken.go.jp (I. Shimamura).


PII: S0168-583X(02)00704-8

## References

[1] M. Charlton, J. Eades, D. Horváth, R.J. Hughes, C. Zimmermann, Phys. Rep. 241 (1994) 65.
[2] R. Abrines, I.C. Percival, Proc. Phys. Soc. 88 (1966) 861.
[3] J.S. Cohen, in: Y. Itikawa et al. (Eds.), The Physics of Electronic and Atomic Collisions, AIP, Melville, New York, 2000, p. 540; Phys. Rev. A 36 (1987) 2024.
[4] R.J. Whitehead, J.F. McCann, I. Shimamura, Phys. Rev. A 64 (2001) 023401.
[5] R.J. Whitehead, J.F. McCann, Y. Teranishi, I. Shimamura, Intern. Conf. Photo. Elec. At. Coll., Santa Fe, New Mexico, Abstracts of Contributed Papers, 2001, p. 394.