The Interaction of Antihydrogen with Simple Atoms and Molecules

E.A.G. Armour[a], A.C. Todd[a], S. Jonsell[b], Y. Liu[a], M.R. Gregory[a] and M. Plummer[c]
[a] *School of Mathematical Sciences, Nottingham University, Nottingham NG7 2RD, UK*
[b] *Department of Physics, University of Wales Swansea, Swansea SA2 8PP, UK*
[c] *CLRC Daresbury Laboratory, Warrington WA4 4AD, UK*

Experimentalists at CERN prepared antihydrogen ($\bar{\mathrm{H}}$) in 2002 and are carrying out further work to trap it so that its properties can be studied. See, for example, refs. [1, 2]. There is interest in the interaction of $\bar{\mathrm{H}}$ with atoms and molecules for a number of reasons. Firstly, it is a novel area involving the interaction of matter and antimatter. Secondly, trapping requires cooling to sub-Kelvin temperatures and experimentalists are looking for suitable atoms or molecules to cool antihydrogen. Thirdly, gases such as He and H_2 may be an impurity in their apparatus.

The first calculations we carried out were on $\mathrm{H}\bar{\mathrm{H}}$ scattering at very low energies [3, 4]. The principal causes of loss of H in this process are rearrangement into $p\bar{p}$ + Ps and antiproton annihilation due to the strong interaction [5, 6].

We are in the process of calculating cross sections for the rearrangement reactions

$$\mathrm{He} + \bar{\mathrm{H}} \rightarrow \begin{cases} \mathrm{He} + \bar{p} + \mathrm{Ps} \\ \mathrm{He}\bar{p} + e^+ \\ \alpha\bar{p} + \mathrm{Ps}^- \end{cases}$$

at very low energies. These cross sections are simply related to the T-matrix

$$T_{fi} = \langle \Phi_f | V_f | \Psi^{(+)}_{\mathbf{k}_i},$$

where $\Psi^{(+)}_{\mathbf{k}_i}$ is the exact scattering wave function for the incident energy under consideration. V_f is the potential that couples the two systems resulting from the scattering, e.g. $\mathrm{He}^+\bar{p}$ and Ps, omitting any long-range Coulomb term. Φ_f is the final wave function if V_f is set to zero.

T_{fi} was calculated using the distorted wave Born approximation of Jonsell *et al.* [4]. In this method, the exact scattering wave function is approximated by the wave function for the entrance channel, calculated using the BornOppenheimer (BO) approximation.

The leptonic wave function for the incident channel was calculated very accurately using basis functions, χ_i, of the form

$$\chi_i = \frac{1}{2\pi}[\lambda_1^{a_i}\lambda_2^{b_i}\lambda_3^{c_i}\mu_1^{d_i}\mu_2^{e_i}\mu_3^{f_i} \times \exp(-\alpha_1\lambda_1 - \alpha_2\lambda_2 - \alpha_3\lambda_3 + \beta_1\mu_1 + \beta_2\mu_2 + \beta_3\mu_3)S(p_i) + 2 \leftrightarrow 3]$$

where particle 1 is the positron, 2 and 3 are the electrons, λ_i and μ_i are prolate spheroidal coordinates for particle i, $a_i, \ldots, f_i$ are non-negative integers, $\alpha_1, \ldots, \beta_3$ are parameters and $2 \leftrightarrow 3$ indicates the corresponding exchange term. Depending on the value of p_i in

$S(p_i)$, χ_i is a σ or π type CI function or a Hylleraas-type function. Both positron-positron and electron-electron correlation are taken into account.

The continuum wave function for the relative motion of the He and the $\bar{\mathrm{H}}$ was calculated using the BO potential of Strasburger *et al.* [7]. Very accurate or exact wave functions were used for the systems in the rearrangement channels. A description of this work at an early stage is given in ref. 8.

The latest results for the rearrangement cross sections, both obtained directly by the above method and using a further simplifying approximation, the overlap approximation [9], will be reported at the conference.

In addition, mention will be made of calculations of cross sections for antiproton annihilation by the strong interaction in very low-energy $\mathrm{He}\bar{\mathrm{H}}$ and $\mathrm{H_2}\bar{\mathrm{H}}$ scattering [10, 11].

---

[1] T. Pohl, H.R. Sadeghpour and G. Gabrielse, Phys. Rev. Lett. **97**, 143401 (2006).

[2] M. Amoretti *et al.*, Phys. Rev. Lett. **97**, 213401 (2006).

[3] E.A.G. Armour and C.W. Chamberlain, J. Phys. B **35**, L47 (2002).

[4] S. Jonsell, A. Saenz, P. Froelich, B. Zygelman and A. Dalgarno, Phys. Rev. A **64**, 052712 (2001).

[5] S. Jonsell, A. Saenz, P. Froelich, B. Zygelman and A. Dalgarno, J. Phys. B **37**, 1195 (2004).

[6] E.A.G. Armour, Y. Liu and A. Vigier, J. Phys. B **38**, L47 (2005).

[7] K. Strasburger, H. Chojnacki and A. Sokolowska, J. Phys. B **38**, 3091 (2005).

[8] E.A.G. Armour, S. Jonsell, Y. Liu and A.C. Todd, Nucl. Inst. and Meth. B **247**, 122 (2006).

[9] E.A.G. Armour and S. Jonsell, J. Phys. A **40**, 701 (2007).

[10] E.A.G. Armour, M.R. Gregory and Y. Liu, Nucl. Inst. and Meth. B **247**, 123 (2006).

[11] S. Jonsell, Nucl. Inst. and Meth. B **247**, 138 (2006).