# Hydrogen - antihydrogen collisions

P. Froelich[1], S. Jonsell[1], A. Saenz[2], A. Dalgarno[3] and B. Zygelman[3]

[1] *Department of Quantum Chemistry, Uppsala University*
*Box 518, 75120 Uppsala, Sweden,*
*Tel +46-18-4713262, Fax +46-18-502402*
*E-mail: piotr@kvac.uu.se*
[2] *Max-Planck Institute for Quantum Optics*
*Hans-Kopfermann-Str. 1, D-85748 Garching, Germany*
[3] *Harvard - Smithsonian Center for Astrophysics*
*60 Garden Street, Cambridge, MA 02138, U.S.A.*

The current search for antimatter in the outer space, the ongoing efforts to produce antihydrogen in laboratory, and the forthcoming experiments with cold antihydrogen are reviewed. Matter - antimatter interaction is studied using the example of hydrogen - antihydrogen collisions. Cross sections for the rearrangement reaction resulting in formation of protonium and positronium in the final channel, according to $\mathrm{H} + \bar{\mathrm{H}} \rightarrow p\bar{p} + e^+e^-$, are calculated in the fully quantum mechanical approach. Implications on the experiments intending to trap and cool the antihydrogen are discussed.

In the present work we investigate the question of stability of antimatter in contact with matter. The fundamental collisional interaction between hydrogen H and antihydrogen $\bar{\mathrm{H}}$ has been considered as the prototype reaction.

The recent advances in producing, trapping and cooling antiprotons and positrons opened the possibility of antihydrogen formation in laboratory. This may allow the studies of antimatter and tests of fundamental physical principles such as charge - parity - time (CPT) invariance or the weak equivalence principle (WEP) for antiparticles. Such experiments are planned at CERN AD (Antiproton Decelerator) within the ASACUSA, ATHENA and ATRAP collaborations.

To study the matter - antimatter interactions in general, and in particular to understand the prerequisites for trapping and cooling antihydrogen, the knowledge of the rates for elastic and inelastic atom - antiatom collisions is of paramount importance - but the previous treatments of the problem have been very scarce.

The elastic scattering is responsible for cooling and the inelastic one, particularly the rearrangement process resulting in formation of protonium, is responsible for losses of antihydrogen (*via* annihilation during the cascade in protonium).

In the present work we have focused interest on the rates for $p-\bar{p}$ and/or $e^+-e^-$ annihilations during $\mathrm{H} - \bar{\mathrm{H}}$ collisions at low (down to ultra-cold) temperatures. In particular, we have calculated the rates for the collisional rearrangement reaction

$$\mathrm{H} + \bar{\mathrm{H}} \longrightarrow p\bar{p} + e^+e^- \tag{1}$$

which inevitably leads to the annihilation of anti-particles from the bound states of protonium (Pn $\equiv p\bar{p}$) and/or positronium (Ps $\equiv e^+e^-$) formed in the final channel.

We have also computed the rates for the alternative loss of antihydrogen *via* annihilation in flight. These inelastic (loss) rates have been compared with the rate for elastic scattering whose low energy limit has been obtained in terms of the scattering length.

The cross section $\sigma^{inel}$ for the formation of protonium - positronium pair through the rearrangement collision (Eq. 1) has been calculated *by the fully quantum mechanical treatment* through computation of the scattering-theoretic transition matrix elements in the post-collisional approach. At very low energies, the rate for elastic collisions behaves as $\lambda_{el} \sim k \sim \sqrt{T}$ and the rate for inelastic collisions $\lambda_{inel}$ is constant, which implies existence of a certain limiting temperature below which $\lambda_{inel} > \lambda_{el}$ and consequently the annihilation (and loss of antihydrogen) dominate the cooling process.

We have solved the rate equations describing the losses of kinetic energy and the density of antihydrogen. The solutions show how the size of of $\sigma_{el}$, $\sigma_{inel}$ and the ratio $\lambda_{inel}/\lambda_{el}$ decide the lowest temperature attainable in collisional cooling of antihydrogen, and how the density of the latter depends on annihilation occuring largely due to inelastic rearrangement collisions.

During the conference we will present the cross sections for the elastic scattering and the antihydrogen loss (either through the rarrangement (Eq. 1) or annihilation in flight) and discuss the implications of our results on the prospects of trapping and cooling antihydrogen.