Production of antihydrogen molecular ions

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In order to make a direct observation of the effect of gravitation on antimatter, the Gbar (Gravitational behavior of antihydrogen at rest) [1] experiment aims at measuring the influence of Earth's gravity in the trajectory of antihydrogen atoms. The Gbar experiment relies on the production of antihydrogen ions $\overline{H}^{+}$which are confined in a magnetic trapped before being neutralized and released, hence dropping in the gravitational field of the Earth. The first observation of antihydrogen in the Gbar setup was made very recently in 2022 [2]. Our group has been part of the Gbar collaboration for over 10 years, since its creation in 2012.

Within the framework of the Gbar project, we propose to study a strategy to achieve the first **observation of the antihydrogen molecular ion**, $\overline{H}_2^-$ (two antiprotons and a positron). A good scenario seems to be the formation of $\overline{H}_2^-$directly within the antiproton beam, and then use the switchyard to separate the produced $\overline{H}_2^-$and $\overline{H}^{+}$. In that case, $\overline{H}_2^-$ would be created in a merged beam configuration, from collisions between antiprotons, antihydrogen atoms and antihydrogen ion, at very low energies defined by the energy spread of the antiproton beam. Several processes can lead to the formation of $\overline{H}_2^-$ in such a beam, among which the most important one would be: $\overline{H} + \overline{H} \rightarrow \overline{H}_2^- + e^+$ (associative ionization).

This PhD project involves two main developments. First, we wish to calculate the cross-section of the above reaction by using the semi-classical model of Mihajlov et al. [2, 3]. From these predictions we will be able to estimate the probability to form the first chemical compound of antimatter ever produced. In addition, the efficiency of the whole process strongly depends on our capability to store and cool down antimatter particles to very low energies. Hence, we will develop several methods to cool down charged antiparticle beams confined in magnetic traps, using methods issued from plasma physics and optimal control theory [4].

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[2] P. Comini and P.-A. Hervieux, New J. Phys. **15**, 095022 (2013).
[3] Mihajlov et al., J. Clust. Sci. **2**, 47 (2012); P. Comini, P.-A. Hervieux and K. Lévêque-Simon, New J. Phys. **23**, 029501 (2021).
[4] G. Manfredi, P.-A. Hervieux, Phys. Rev. Lett. **109**, 255005 (2012).