Enabling more efficient antihydrogen production: MD simulation of transmission of antiprotons through thin carbon foils

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The production of stable antihydrogen atoms relies on the slowing down of antiprotons ($\bar{p}$) with initial energies of the order of MeV's or keV's to thermal energies. In particular, the antiproton storage ring ELENA currently under construction at CERN will produce a 100 keV antiproton beam, that should be further slowed down to energies of 0 – 5 keV to enable antihydrogen production. The slowing down of energetic ions or antiions is determined by the stopping power. Optimizing the transmission efficiency makes it important to know the low-energy stopping power of antiprotons in materials.

While there are numerous studies of the electronic stopping power of antiprotons, there have been none for the nuclear stopping power. We have now used quantum chemical methods to calculate interparticle potentials between antiprotons and different atoms, and show that these are attractive at all interatomic distances. Using scattering calculations with the obtained potentials, we further derive the nuclear stopping power of antiprotons in solids. The results show that the antiproton nuclear stopping powers are much stronger than those of protons. Moreover, contrary to the case of protons, the antiproton nuclear stopping can be stronger than their electronic one [1].

Using the obtained interparticle potential and experimental electronic stopping powers (including the straggling of the electronic stopping), we simulate with molecular dynamics (MD) the transmission and capture probability of 100 keV antiprotons in nanometer thin foils. The simulations show that after slowing down to keV energies, the antiprotons have a high probability of being captured in a bound orbit with sample atoms. Since the antiproton-atom interaction at small distances is essentially a purely attractive $1/r$ potential, comparable to the gravitational potential, the antiprotons can even end up in Kepler-like elliptical orbits. Finally, we determine the optimal film thickness of C, mylar, Be, Al an Si foils for the production of 0 – 5 keV antiprotons [1,2,3]. Comparison of the results allows predicting optimal foil thicknesses and materials for antihydrogen production experiments under construction at CERN.

[1] K. Nordlund et al, Physical Review A **96**, 042717 (2017).
[2] K. Nordlund, Results in physics **8**, 683 (2018).
[3] K. Nordlund et al, to be published (2019).