Laser-assisted collisional antihydrogen formation

Isao Shimamura
RIKEN (Institute of Physical and Chemical Research)
Wako, Saitama 351-0198, Japan

Capture of an antiproton $\overline{p}$ by a target atom A in a slow collision between them with the emission of an electron e^-, namely,

$$A + \overline{p} \rightarrow A^+\overline{p} + e^-, \tag{1}$$

results in the formation of an antiprotonic atom $A^+\overline{p}$ in some quantum mechanical state. For a positronium target, this $\overline{p}$ impact process, namely,

$$\mathrm{Ps} + \overline{p} \rightarrow \overline{\mathrm{H}} + e^-, \tag{2}$$

is the production of the antihydrogen $\overline{\mathrm{H}}$, and is charge-conjugate to the production of the hydrogen atom in the proton-positronium collision.

In principle, processes (1) and (2) need to be treated theoretically in the fully quantum mechanical framework. In practice, it is an extremely difficult task, and I am aware of only one recent paper that reports a reliable fully quantal approach to the protonium formation in antiproton collisions with hydrogen atoms.

Semiclassical methods in which the electronic motion is treated quantally but the relative $\overline{p}$-A motion is treated classically lead to perhaps essential physics of the capture/ionization processes in some sense. Even within the framework of the semiclassical treatment, there are many possible approaches of different levels of complexity and reliability. We have used an extremely simple diabatic model to estimate the low-energy cross sections for various atomic targets.

Fully classical "simulation" of the whole process would be of interest if its limitations are carefully kept in mind. Indeed, its applications to three-body systems have led to deeper understanding of the dynamics. It has also been applied (with some modification) in the literature to atoms with more than one electron.

This simulation is possible also for the process in the presence of an external field, such as a laser field, though the absolute value of the cross section should not be taken too seriously in some cases.