Antiprotonic atoms and molecules: Theory and forthcoming experiments

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Antiprotonic ($\bar{p}$) atoms are formed in low-energy collisions between antiprotons and normal atoms or molecules. There is renewed interest in this subject due to upcoming experiments (ASACUSA Collaboration), which, for the first time, can directly measure the energy-dependent cross sections. This can be done for capture by the hydrogen molecule *and* atom, as well as for capture by the noble-gas atoms. The fermion molecular dynamics (FMD) method has enabled us to go beyond the atomic hydrogen target and study electron-correlation effects with noble-gas targets and molecular effects with isotopic molecular hydrogen targets. FMD is a quasiclassical method for treating quantum-mechanical systems using classical equations of motion with momentum-dependent model potentials added to the usual Hamiltonian to simulate quantum-mechanical effects. The differences between capture by H_2 and the H atom are found to be dramatic. The effects due to the two-center structure, rotational motions, and vibrational motions are distinguished. Antiproton captures by helium, neon, argon, krypton, and xenon atoms have also been treated using the FMD method. The residual electrons are generally left in a shake-up state. Comparisons will be made with existing muon experiments, and prospects for coming experiments with antiprotons will be discussed.