Guiding Center Drift Atoms in Antihydrogen Production

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The ATHENA and ATRAP collaborations at CERN have produced weakly bound cold antihydrogen atoms. The weakly bound atoms reside in a very strong magnetic field (3 − 5 Tesla) and are very different from high-n Rydberg atoms with a Kepler orbit. More properly these weakly bound and strongly magnetized pairs should be called "guiding center drift atoms."[1] The characteristic cyclotron radius for the positron is much smaller than the separation between the positron and antiproton, and the cyclotron frequency for the positron is much larger than the other dynamical frequencies. Under these circumstances the rapid cyclotron motion can be averaged out and the positron dynamics treated by guiding center drift theory. The dynamics is quasi-classical because the atoms are so weakly bound. In a particularly simple limit the positron guiding center oscillates back and forth along the magnetic field in the Coulomb well of the antiproton and more slowly **E** x **B** drifts around the antiproton. In another limit, the positron and antiproton **E** x **B** drift together across the magnetic field, and in a third limit the antiproton executes a large cyclotron orbit in the vicinity of the positron, which is effectively pinned to the magnetic field. This paper will analyze and classify the possible motions; fortunately, the dynamics of the weakly bound and strongly magnetized pair is completely integrable. Since the dynamics is quasi-classical, quantum numbers are easily assigned using the Bohr-Sommerfeld rules. The weakly bound atoms are readily polarized by an electric field, and then a gradient in the field exerts a force on the atom. This can lead to a radial trapping of the atoms in the space charge field of the positron plasma. To understand the trapping, recall that a polarizable material is attracted to a region of large electric field. In the antihydrogen experiments, field ionization is used as a diagnostic for binding energy. The critical field for ionization will be calculated as a function of the quantum numbers for the atomic state.

This work was supported by National Science Foundation grant PHY-0354979.

[1] M.E. Glinsky and T.M. O'Neil, Phys. Fluids B 3, 1279 (1991); S.G. Kuzmin, T.M. O'Neil and M.E. Glinsky, Phys. Plasmas 11, 2382 (2004); S.G. Kuzmin and T.M. O'Neil, Phys. Rev. Lett. 92, 243401 (2004).