Field induced electron - ion recombination, a novel route towards neutral (anti-) matter

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In 1996 Baur et al.[1] observed nine statistically significant events of the formation of antihydrogen atoms, the bound state of a positron and an antiproton. However, the number of detected antihydrogen atoms was small and they were produced at relativistic velocities, making meaningful measurements essentially impossible. A breakthrough, paving the way to serious research into the properties of neutral antimatter, would be the wall-free confinement of cold antihydrogen atoms. To produce such cold antihydrogen atoms and catch them before they annihilate with matter is the primary goal of the ATRAP (Antihydrogen Trap) collaboration[2]. Once trapped, cold antihydrogen atoms can be used for experiments such as tests of CPT invariance or gravity measurements.

Making an (anti-) hydrogen atom by recombining an electron (positron) and a proton (antiproton) is not simple. The recombination is only possible when a third object carries away the excess energy of the captured electron. This third particle can be a second, spectating, electron (this process is known as three-body recombination), or a photon (radiative recombination).

Here we present the realization of a new recombination scheme (see Fig. 1) using pulsed electric fields as slow as 1 ns. Pulsed field recombination (PFR) can be regarded as intermediate between the radiative and the three-body process. One can say the effect of the third body, stimulating the recombination through its time dependent electric field, is now applied 'by hand' in the formed of tailored pulses. The observed recombination efficiency ($\frac{\mathrm{numberofrecombinedatoms}}{\mathrm{numberoffreeions}} = 0.003$) [3] is orders of magnitude higher than realized by other means.

The PFR technique can also be used as a tool for the creation of a Rydberg state in an atom or a molecule. Not always is it trivial to prepare a Rydberg state in a complex system such as a large molecule by conventional means. Recently we have shown that using the PFR method to recombine a free electron with a large ionic carbon cluster such as C_{60}^{+} induces a highly excited bound state of such a molecule ($n \approx 180$) [4]. This was the first time the existence of C_{60} Rydberg states was observed convincingly.

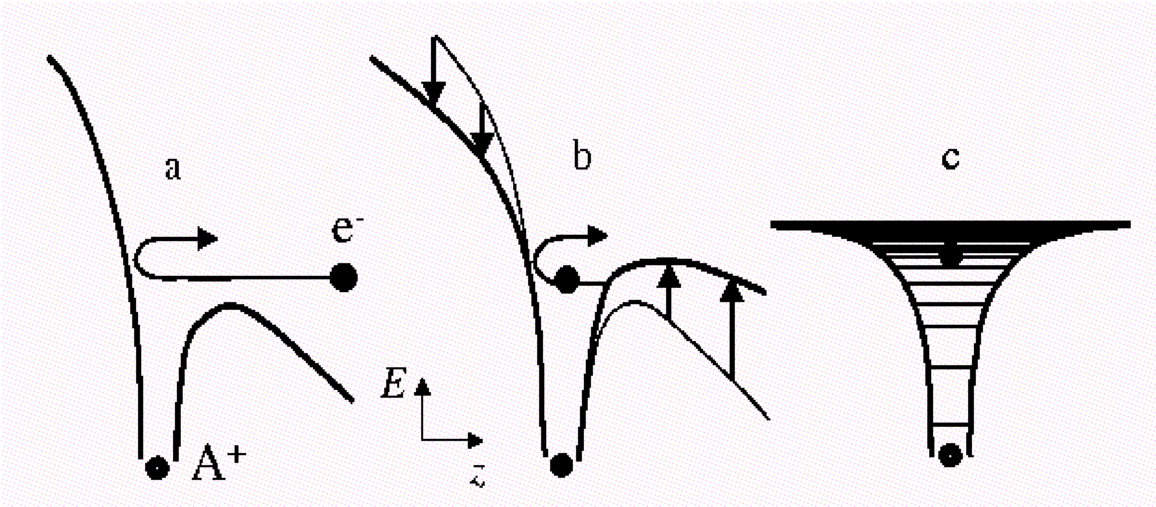

Figure 1: The essence of a pulsed field scheme in the very low frequency limit. Suppose an electron is approaching an ion in the presence of an electric field, such that the electron just passes over the saddle point of the barrier. Eventually the electron will leave the potential over the same barrier. The electron spends about 1 nanosecond at the turning point near the ion. The key point of the proposed recombination scheme is to reduce the static field while the electron is near the proton. In this way the electron ends up below the saddle point in a Rydberg state and can not escape again.

[1] G. Baur et al., *Phys. Lett.* B **368**, 251 (1996).
[2] homepage: http://hussle.harvard.edu/~atrap/.
[3] C. Wesdorp, F. Robicheaux, and L. D. Noordam, *Phys. Rev. Lett.* **84** (2000).
[4] C. Wesdorp, F. Robicheaux, and L.D. Noordam, submitted to *Chem. Phys. Lett.*.