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Hybrid Penning-Linear-Paul trap for ion recapture in a near-zero bias magnetic trap for hydrogen/antihydrogen spectroscopy

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The reason why there is no primordial antimatter in the Universe remains a mystery. Measurements with antimatter [1][2] show full compatibility with its matter counterparts at high precision and that the antimatter feels Earth's gravitational attraction similarly to matter [3] at low precision.
Antihydrogen (Hbar) is produced by trapping antiprotons and positrons in neighboring wells in a Penning-Malmberg trap and slowing mixing then. An Ioffe-Pritchard octupole magnetic trap superposed to the Penning trap allows the trapping of the produced neutral Hbars with energy below 500 mK [4]. Since trapped antiprotons and positrons are needed to create Hbars, a bias magnetic field of ˜1 T is used in the trap region. This high magnetic field adds some systematic uncertainties in comparing the two-photon 1s-2s transition in H and Hbar since accurate measurements with H [5] are performed in a very low magnetic field environment. The precision of the comparison can be improved by trapping hydrogen in the same Hbar trap [6][7][8] and repeating the exact measurements with both counterparts, avoiding many systematic uncertainties such as this magnetic field effect, AC Stark shift from the same laser and enhancement cavity operation [9]. However, the strong bias magnetic field still affects the transition's lineshape and center. It is possible to ramp down the bias magnetic field and perform the 1s-2s spectroscopy with Hbar's since we can always detect the annihilation of the ionized atoms efficiently. Nevertheless, repeating the exact measurement in a near-zero bias with H is not straightforward since we can not detect the annihilation. If we keep the bias magnetic field, it is possible to recapture a fraction of the ionized H during the spectroscopy [10] by using a weak Penning trap potential, but for a near-zero magnetic field, recapturing the protons can not be accomplished.
Here, we suggest using a hybrid Penning-Linear-Paul trap, using a segmented electrode in the Penning-Malmberg trap to radially confine the ions to perform high precision 1s-2s spectroscopy in H in a near-zero field trap. We will discuss the stability of the recaptured particles in a Linear-Paul trap with a weak magnetic field along the axis, the effect of the electric field on the lifetime of the H/Hbar, lineshape of the transition, the effect of a superposed octupole field to the RF trap, patch potentials, and possible magnetic fields measurements at low fields.

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