

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

Monday 10 June 2024 18:00 (2 hours)

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.

[1] - Borchert et al, Nature 601, 53-57 (2022).

[2] - Ahmadi, M. et al., Nature 557, 71-75 (2018)

[3] - Anderson, E.K. et al., Nature 621, 716-722 (2023)

[4] - Andresen, G. B. et al, Nature 468, 673-676 (2010)

[5] - Parthey, C. G. et al., Phys. Rev. Lett. 107, 203001 (2011)

[6] - Azevedo, L.O.A. et al, Commun Phys 6, 112 (2023)

[7] - S A Jones, New J. Phys. 24 023016 (2022)

[8] - W. A. Bertsche et al 2022 J. Phys.: Conf. Ser. 2244 012080

[9] - ALPHA Collaboration, Nature Physics, Accepted - To be published

[10] - Cesar, C. L., J. Phys. B49, 074001 (2016)

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Session Classification: Poster Session 1