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Investigating energy exchange dynamics in trapped antihydrogen for precision tests of fundamental symmetries

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"The ALPHA (Antihydrogen Laser PHysics Apparatus) experiment uses magnetically trapped antihydrogen to test fundamental matter–antimatter symmetries. As the simplest anti-atom, antihydrogen is a promising candidate for testing CPT symmetry in an atomic system and the Weak Equivalence Principle (WEP) with antimatter. ALPHA has already achieved major milestones, including the first observation of gravity's effect on the motion of antimatter [1], the first precision measurement of the 1S-2S transition frequency [2], spectroscopy of the 1S-2P transitions [3], and observation of ground state hyperfine splitting [4] in antihydrogen.

Moving forward, ALPHA aims to improve experimental precision for more stringent tests of CPT symmetry and the WEP. Many of ALPHA's measurements critically rely on simulations to extract fundamental physics parameters or interpret spectroscopic line shapes. These simulations make intriguing predictions about the non-linear dynamics of trapped anti-atoms that are not currently well understood. In particular, simulations predict that some anti-atoms exchange energy between degrees of freedom, while others do not [5]. The existence of these two categories of anti-atoms has not previously been observed experimentally. Furthermore, the energy distributions of trapped anti-atoms are not well understood but are a crucial variable for future precision experiments. Laser cooling of antihydrogen, microwave and 1S-2S spectroscopy, and measurements of the gravitational acceleration of antimatter all rely on understanding energy exchange and distributions in ALPHA.

This poster presents the first direct experimental evidence differentiating anti-atoms that exchange energy components from those that do not. The technique used to distinguish these two categories of anti-atoms is also presented as a new method to characterize energy distributions of trapped antihydrogen. These studies work toward a comprehensive understanding of energy exchange dynamics in ALPHA, both benchmarking simulations against experiments and informing future high precision tests of fundamental symmetries.

[1] Anderson, E.K. et al, Nature 621, 716-722 (2023).
[2] Baker, C.J. et al, Nat. Phys. 21, 201-207 (2025).
[3] The ALPHA Collaboration, Nature 578, 375-380 (2020).
[4] Ahmadi, M. et al, Nature 548, 66-69 (2017).
[5] Zhong, A. et al, New J. Phys. 20, 053003 (2018)."

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